4

Natural light and health

4.1 SUNLIGHT AND VITAMIN D

Definition and history of vitamin D

The first scientific description of a vitamin D deficiency, rickets, was provided in the seventeenth century (Whistler, 1645; Glisson, 1650). The healing effects of vitamin D, however, were not understood until the beginning of the twentieth century, the period between 1910 and 1930 when researchers were trying to identify the causes of rickets, an abnormal bone formation in children that results from inadequate bone calcium. Rickets is due to the failure to mineralize bone, thus causing osteomalacia, the softening of the bone structure. A dietary agent in cod liver oil was found to alleviate this problem and was named vitamin D. In 1923 an anti-rickets effect similar to that of cod liver oil was observed in ultraviolet (UV) radiation. Goldblatt and Soames (1923) observed that when a precursor of vitamin D in the skin, known as 7-dehydrocholesterol, was irradiated with sunlight or ultraviolet light, a substance

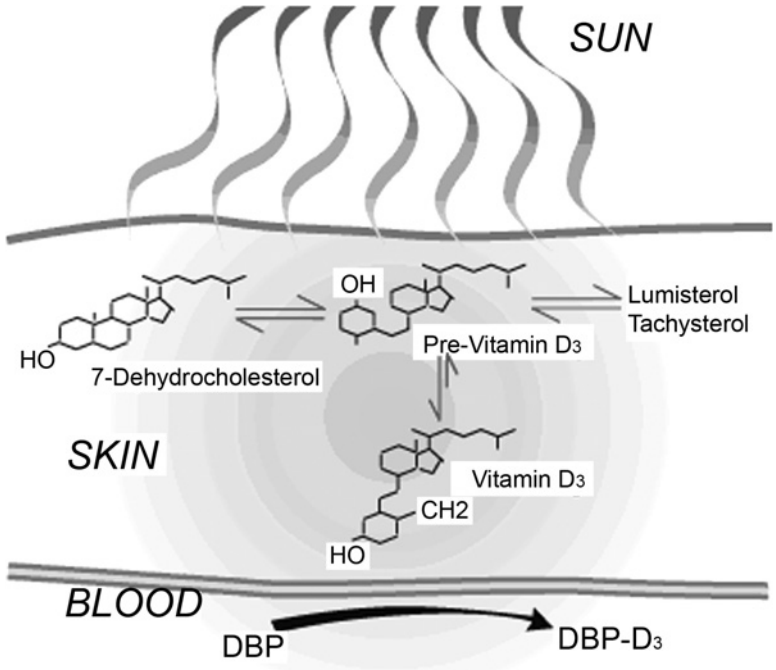

Figure 4.1 Vitamin D production through skin photosynthesis.

equivalent to vitamin D was produced. Vitamin D comprises a group of fat-soluble seco-sterols, scarce in most foods but manufactured in the skin of vertebrates through photosynthesis of solar ultraviolet type B radiation (UV-B).

Ultraviolet light is divided into three wavelength spectra: UV-A, UV-B, and UV-C. The shortest and most potent of the three, UV-C (<280 nm), can burn the skin even at small doses. It is completely absorbed by the ozone layer. UV-A (320 nm to 400 nm), known as 'black light,' has a longer wavelength than B or C and is responsible for skin darkening and pigmentation; consequently, we refer to it as the tanning light. UV-B (290 nm to 315 nm) is responsible for photosynthesis and stimulates our skin to produce vitamin D (Figure 4.1). It is also responsible for skin burning and aging. The amount of UV-B present in UV light depends on the angle of incidence of the solar rays and is most prevalent during midday hours at higher latitudes (Figure 4.2). The content of UV-B rays in sunshine is greatest at latitudes of up to 30 degrees north and south of the equator. At an altitude of 1000 meters the content of UV-B rays is 15% higher, whereas the content of UV-A rays is almost the same as at sea level. At latitudes greater than 55 degrees, very little UV-B radiation reaches the earth's surface during the winter months.

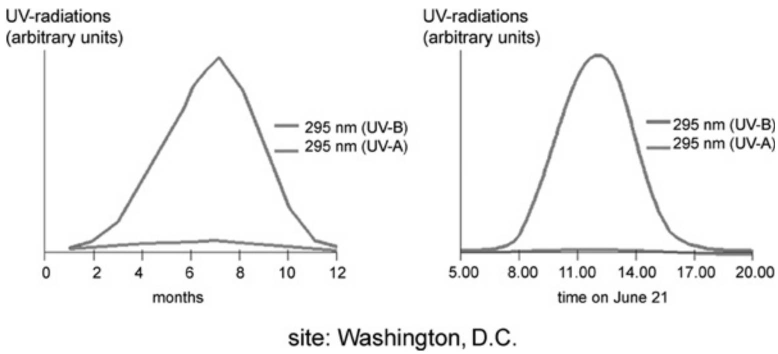

Figure 4.2 Variation of UV radiation according to months and time of day (adapted from Serafino and Frederick, 1987; courtesy of William B. Grant).

A much higher proportion of UV energy passes through glass from daylight radiation than from incandescent, halogen, or fluorescent light sources. Glass, however, filters out about 95% of the UV-B radiation present in the atmosphere. As a result, the occupants of buildings receive nine to ten times less UV-B radiation than if they were outside.

Role of vitamin D

Vitamin D regulates the absorption of nutrients in the small intestine and their re-absorption in the kidneys. It helps maintain serum calcium and phosphorus concentrations within the normal range, thereby enhancing the capability of the small intestine to absorb these minerals from the diet. Both calcium and phosphorus are essential elements for the growth and development of bone structure (DeLuca, 1988; Reichel *et al.*, 1989). The absorption of these minerals enables bones and teeth to harden by increasing the deposition of calcium and assists in the migration of calcium across body cell membranes. The vitamin D compound has a brief residence time in the blood as it is normally stored either in fat or metabolized in the liver (Mawer *et al.*, 1972).

Vitamin D is essential for proper bone development and growth. We receive 80–100% of our vitamin D needs through our skin by way of photosynthesis (Glerup *et al.*, 2000). Vitamin D is called the 'sunshine vitamin' because it is formed in the skin by the action of ultraviolet rays from the sun.

In addition to the vitamin D we receive from the sun, it can also be found in foods such as eggs, meat, some cereals, oily fish, butter, and margarine. However, the dietary contribution to our vitamin D need is very small, if not negligible, compared with the amount produced through photosynthesis. It is, therefore, imperative that we receive adequate exposure to sunlight whether outdoors or indoors. Since we spend more than to 80% of our lifetime indoors (Newton *et al.*, 2001), architects are responsible for providing this vital ingredient to the occupants of buildings.

4.2 SUNLIGHT AND HYPOVITAMINOSIS D

According to an old adage, where sunlight goes the doctor does not. Our ancestors spent considerable time in the sun, but our relationship with the sun has changed over time as a result of modern working conditions, urbanization, and population migrations from rural to urban areas. This process began with the Industrial Revolution in the mid-eighteenth century. Today many of us spend the majority of our lifetime indoors, particularly in the industrialized world where the economy is industry- and service-based rather than based on agriculture. Most workers spend at least 5 days a week indoors at their workplace when daylight is at its peak. Because of its importance in the production of vitamin D, sunlight is vital to human life. When sunlight is inadequate, vitamin D levels decline, thereby provoking or exacerbating a number of health problems including bone thinning, many forms of cancer, high blood pressure, depression, and such immune-system disorders as multiple sclerosis, rheumatoid arthritis, and diabetes (Stein, 2004).

A variety of factors can limit our exposure to sunlight. We may not have access to adequate amounts of sunlight because our mobility is limited through age or illness, or because of the built environment in which we live and work. These conditions limit exposure to sunlight and cause a deficiency in vitamin D (hypovitaminosis D). Various reports suggests that more than 40% of American adults have low blood levels of vitamin D, a condition found among people living in northern latitudes above 30°N or in the southern latitudes above 30°S.

Patients who are hospitalized for prolonged periods are also known to be deficient in vitamin D. To examine this claim, a group of researchers from Massachusetts General Hospital and the Harvard Medical School (Giovannucci, 1998) assessed vitamin D intake, ultraviolet-light exposure, measured levels of serum 25-hydroxyvitamin D, parathyroid hormone, and ionized calcium in 290 patients on a general medical ward. A total of 57% (164 patients) were found to be vitamin D deficient, with serum concentration of 25-hydroxyvitamin D less than 25 ng/ml. Of these 164 patients, 64% were considered severely deficient. The study concluded that hypovitaminosis D is fairly common among hospital patients, not for dietary reasons but because of their limited exposure to sunlight due to restricted mobility and the inability to move about freely.

Seasonal variation in vitamin D is another strong indicator of the link between the degree of exposure to sunlight and vitamin D. Seasonal variations in serum 25-hydroxyvitamin D levels were found in a study conducted by a group of Italian medical researchers (Romagnoli *et al.*, 1999). Serum mean values were higher in summer in all groups, except in patients with longer hospitalization times. In each group, significantly higher prevalence of hypovitaminosis D was observed in winter than in summer, but once again long-term hospital patients experienced hypovitaminosis D in both winter and summer because their access to sunlight was restricted.

Cultural and geographical factors can also be causes for vitamin D deficiency. According to a health research forum in the United Kingdom (Gillie, 2006), 50% of people in Britain and Ireland were deficient in vitamin D because of climate conditions. It is worth noting that people from those countries who went on holiday to sunny climes more frequently exhibited less deficiency. A number of reports of vitamin D deficiency among Indo-Asians after migration to the United Kingdom was found to be related to inadequate sunlight (Iqbal *et al.*, 1994; Serhan *et al.*, 1999), a finding that indicates a strong link between sunlight and vitamin D and a weaker one between diet and vitamin D.

Women in countries of the Arabian Gulf region who totally cover their bodies, including their face and hands, were found to suffer from a more severe vitamin D deficiency than their western counterparts (El-Sonbaty and Abdul-Ghaffar 1996; Ghannam *et al.*, 1999; Gannage-Yared *et al.*, 2000; Saadi and Dawodu, 2005; Saadi *et al.*, 2006). Low exposure of the skin to sunlight because of dress code seems to be a major contributing factor to vitamin D deficiency. Although this condition could be partially due to dietary factors, hypovitaminosis D caused by lack of sunlight is believed to be a major contributing factor because we receive most of our vitamin D from sun-induced photosynthesis and not from diet. Similar results were obtained in a study that examined whether the latitudinal variation between Turkey and Germany and the wearing of the veil affected vitamin D levels in Turkish migrant populations in Germany (Erkal *et al.*, 2006). Turkish women in Germany experienced lower vitamin D levels than their female counterparts in Turkey where sunlight is more abundant. Turkish women in general, however, exhibited lower levels of vitamin D compared with Turkish men because the veil restricts their exposure to sunlight. This is yet another indicator of the strong link between sunlight exposure and vitamin D. It also suggests that diet is less effective in providing vitamin D because it is reasonable to assume that Turkish women and Turkish men have the same diet.

4.3 BONE DISEASE AND THE ROLE OF SUNLIGHT AND VITAMIN D

The relationship between hypovitaminosis D and bone frailty, especially hip fractures, among older people has been demonstrated in numerous studies (Holick, 2004). This problem has been shown to be particularly acute at the end of the winter season when days are shorter and exposure to sunlight is minimal (Webb *et al.*, 1990) and when people have had exposure to little sunlight for months. An Australian study examined the association between changes of season, incidence of hip fracture, and vitamin D levels in a population of elderly, not very mobile patients in the Tasmania region (Inderjeeth *et al.*, 2002). Of these patients, 68% either lived in institutional care or were dependent on a care-provider for mobility. Almost half of them (48%) indicated that they went outdoors less than once a week. This study found no significant seasonal variations in vitamin D concentration among these patients because most were bed-ridden or housebound and received little vitamin D from photosynthesis. Regardless of diet, they remained deficient in vitamin D and their bone frailty could not be overcome, another finding that highlights the vital importance of sunlight in the production of vitamin D and the ineffectiveness of dietary solutions.

Elderly people suffer more from vitamin D deficiency than younger populations because the ability of our skin to photosynthesize and produce vitamin D is significantly reduced as we age (MacLaughlin and Holick, 1985). Tests revealed that vitamin D production by skin photosynthesis is four times lower in people over the age of 65 than in a younger population between the ages of 20 and 30 (Holick *et al.*, 1989). If there is an architectural lesson to be learned from this it is that health care facilities, nursing homes and buildings that house elderly people should have higher requirements for sunlight and need to be designed to allow for greater access to sunlight than other types of buildings.

There are numerous scientific indications that point to the strong relationship between sunlight, or lack thereof, and vitamin D, and to the weaker link between diet and vitamin D. For example, rickets, a disease long eradicated in most developed countries, continues to be prevalent in countries where infants are swaddled and women are confined to the home or assigned a dress code that covers the body. A strong relationship between vitamin D and fetal bone development and a greater risk of bone frailty is found among residents of many northern states of the United States because of climate conditions and not because of dietary causes (Kreiter *et al.*, 2000; Weisberg *et al.*, 2004). The role of vitamin D in the regulation of calcium and phosphorous absorption and in metabolism for bone health is especially crucial during pregnancy and lactation because of the rapid development of the bones of the fetus and the newborn child. Women have less skin pigmentation than men; as a result, they need more vitamin D, especially during pregnancy.

4.4 HEART DISEASES AND THE ROLE OF SUNLIGHT AND VITAMIN D

In addition to rickets, and bone loss and fracture, inadequate vitamin D is believed to have multiple harmful effects on our cardiovascular systems. Reports suggest that when vitamin D is deficient, heart failure can result but such failure is reversible when our bodies are replenished with vitamin D (Rostand, 1997). Medical tests show that hypovitaminosis D is common among patients with heart failure, and it is responsible for several heart malfunctions such as hypertension (Shane *et al.*, 1997; Schleithoff *et al.*, 2003; Chen *et al.*, 2005). Hypertension is considered a major risk factor for heart failure. Although factors causing hypertension may be genetic, hypertension can also be caused by the environment. Epidemiological evidence links insufficiencies of vitamin D to hypertension (Rostand, 1997). Supplements of vitamin D were found to reduce systolic blood pressure in elderly women who had low vitamin D levels, while ultraviolet-B radiation was found to reduce arterial pressure in patients with mild hypertension (Krause *et al.*, 1998).

There are indications that vitamin D can help patients with kidney diseases. It can be used as a palliative measure to improve blood pressure and renal osteodystrophy, a bone disease that occurs when the kidneys fail to maintain adequate levels of calcium and phosphorus in the blood. Prasad and colleagues (2001) found seasonal patterns in blood pressure among dialysis and renal transplant patients. These patients registered higher blood pressure in winter than in summer, in all likelihood due to the difference in daylight hours that patients experienced in seasonal cycles. The longer their exposure to daylight, the more normal their blood pressure became.

4.5 MULTIPLE SCLEROSIS AND THE ROLE OF SUNLIGHT AND VITAMIN D

There are millions of people who are afflicted by multiple sclerosis (MS), one of several degenerative diseases that, like diabetes type 1 and rheumatoid arthritis, afflict millions of people. There are about 85 people with MS for every 10 000 people in the USA. It is estimated that the worldwide population with MS is around 2.5 million and that about 50% more females are afflicted with MS than males (Noonan, 2002; MS Society Statistics, 2006).

Data show that MS is more prevalent in latitudinal regions farthest away from the equator and it is believed that there is a correlation between MS and UV-B exposure (Davenport *et al.*, 1922). Davenport found that men in the armed services who grew up in Wisconsin, Michigan and the extreme US northwest had the highest MS incidence among all other men in the armed services. He also noted that men in urban areas had 50% more MS incidence than those in rural areas. He contends that reduced exposure to sunlight and UV-B in cities as a result of pollution and dense urban fabric may be the cause for such higher incidence. Two other studies following that of Davenport also suggested a strong link between sunlight and MS; one focusing on men in the armed forces (Acheson *et al.*, 1960), and the other on veterans (Norman *et al.*, 1983). Both of these studies confirmed a negative correlation between exposure to sunlight and MS incidence: that is, the higher the exposure to sunlight the lower the incidence, and *vice versa*. Figure 4.3, provided by the Sunlight Nutrition and Health

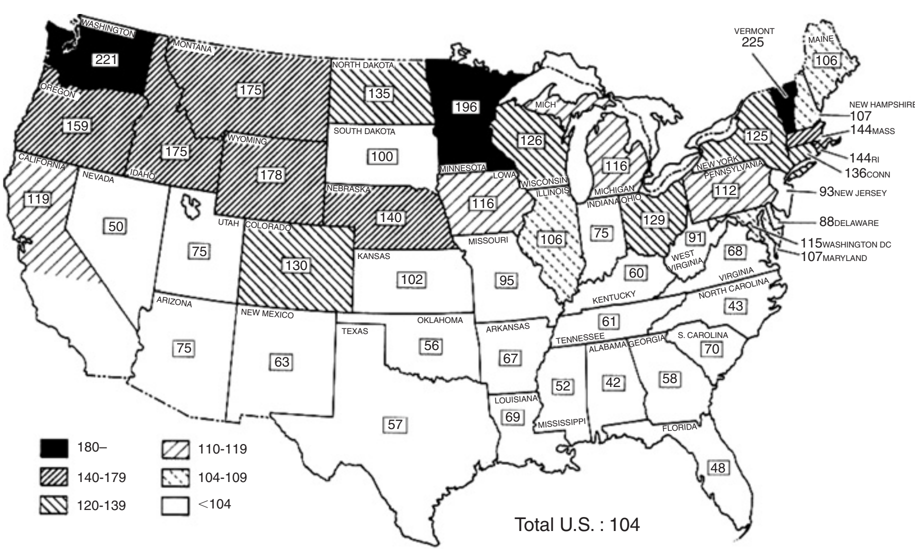

Figure 4.3 Geographical distribution of MS in the United States (http://www.sunarc.org/).

Research Center, a governmental agency of the United States, illustrates a positive correlation between latitude and MS incidence, or, in other words, a negative correlation between sunlight and MS. The figure indicates not only that there is lower incidence of multiple sclerosis in the southern states compared with the northern ones, but also higher incidence in urban and denser regions than in low density ones.

4.6 CANCER AND THE ROLE OF SUNLIGHT AND VITAMIN D

Skin cancer has many causes but UV radiation is one. The harmful effects of UV radiation may be prevented by avoiding excessive exposure to sunlight and other sources of UV radiation. This type of cancer is the type increasing most quickly in the United States and is the most commonly diagnosed malignancy, exceeding lung, breast, colon, or prostate cancer. More than one million Americans will be diagnosed with skin cancer in 2007 (American Cancer Society, 2007).

While skin cancer can be caused by UV radiation, research also suggests that sunlight, by way of vitamin D, can prevent a number of internal cancers (Grant and Garland, 2006). The number of deaths from internal cancers far exceeds the mortality rate from skin cancer, according to a publication by the American Cancer Institute (Table 4.1). The number of deaths

Table 4.1 Estimated numbers of new cases and deaths for common cancer types.

Cancer type	Estimated new cases	Estimated deaths
Bladder	67 160	13 750
Breast (female – male)	178 480–2030	40 460–450
Colon and rectal (combined)	153 760	52 180
Endometrial	39 080	7400
Kidney (renal cell)	43 512	10 957
Leukemia (all)	44 240	21 790
Lung (including bronchus)	213 380	160 390
Melanoma	59 940	8110
Non-Hodgkin lymphoma	63 190	18 660
Pancreatic	37 170	33 370
Prostate	218 890	27 050
Skin (nonmelanoma)	$>$1 000 000	$<$2000
Thyroid	33 550	1530

in 2007 due to nonmelanoma skin cancer is estimated to be less than 2000 and the number of deaths due to melanoma cancer is about 8000; however, over 52 000 deaths from colon and rectal cancer, over 27 000 deaths from prostate cancer, and over 40 000 from breast cancer are likely to occur (American Cancer Society, 2007).

According to William Grant, Director of the Sunlight, Nutrition and Health Research Center (Sunarc) in California, excessive exposure to sunlight causes 1600 deaths a year in the United Kingdom from melanoma skin cancer. Insufficient exposure to sunlight, however, causes 25 000 deaths a year from internal cancers. According to Dr Grant, UV-B radiation was inversely correlated with 16 types of cancer for white Americans, primarily epithelial cancers of the digestive and reproductive systems. Others have also pointed to an association between vitamin D deficiency and other types of internal cancer including colon, breast, and prostate cancer (Garland and Garland, 1980; Garland *et al.*, 1989; Gorham *et al.*, 2005; Holick, 2006; Grant and Garland, 2006).

When examining the geographic distribution of cancer mortality rates in the United States (Figures 4.4–4.5 and 4.6) a positive correlation between latitude and three types of cancer mortality rates becomes apparent. Put differently, there is an inverse correlation between exposure to UV radiation and

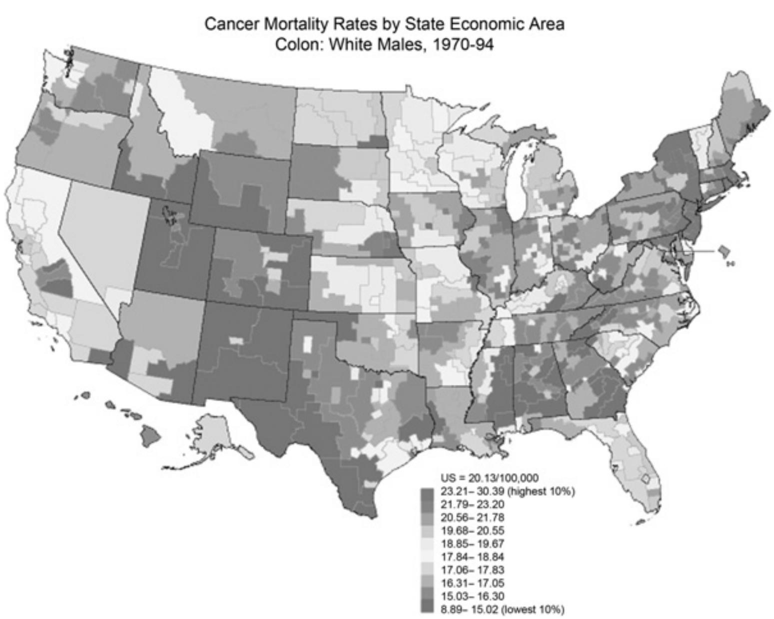

Figure 4.4 Colon cancer mortality by state economic area (age-adjusted 1970 US population) among white males, 1970–1994 (courtesy of William B. Grant).

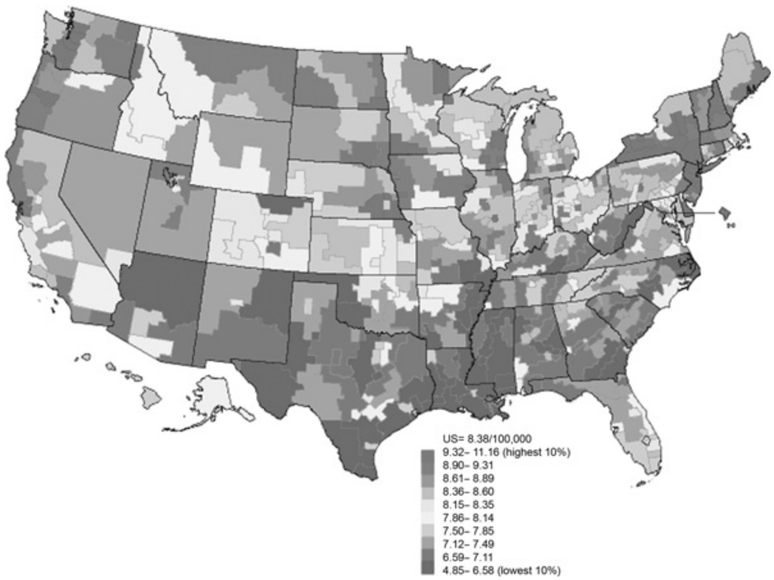

Figure 4.5 Ovarian cancer mortality by state economic area (age-adjusted 1970 US population) among white females, 1970–1994 (courtesy of William B. Grant).

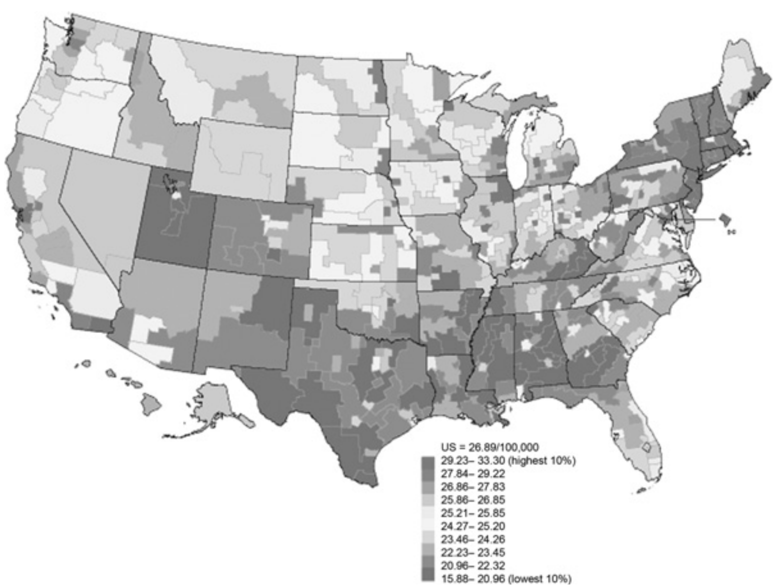

Figure 4.6 Breast cancer mortality by state economic area (age-adjusted 1970 US population) among white females, 1970–1994 (courtesy of William B. Grant).

rates of breast, colon, and ovarian cancer. The farther north, the less the solar radiation and the higher the rate of cancer incidence and mortality. Numerous studies have investigated these correlations and there seems to be general agreement that vitamin D gained through sunlight reduces the incidences of prostate, ovarian, and breast cancers. Table 4.2 (Heisler, 2005) summarizes the results of an extensive literature review of different types of internal cancers, the influence of UV and vitamin D, and the incidence and death rates for each type of cancer. Three types of investigations are reviewed: ecological, case study, and cohort investigations. This summary provides evidence of the strong association between sunlight and cancer. Van der Rhee and de Vries (2006) reviewed 26 publications on this subject and found an inverse correlation between sunlight exposure and mortality or incidence of three types of cancer. Eight of the 26 publications dealt with prostate cancer and each showed an inverse correlation between exposure to sunlight and prostate cancer

Table 4.2 Diseases in the United States associated in the literature with UV radiation arranged in order for US deaths per year (usually 2001). Incidence and mortality are per annum from recent years.

Disease	Incidence/ 100 000	US cases	US deaths	UV influence	Vitamin D influence
Colon cancer	39		53 000	RR, MRR	RR, MRR
Breast cancer	28 (F)		41 800	RR, MRR	RR
Prostate cancer	161		30 700	RR, MRR	RR (M)
Pancreas	11		29 800	RR	
Non-Hodgkin lymphoma	18		22 300	RR	
Cancer of ovary	13		14 400	RR, MRR	
Cancer of esophagus	5		12 500	RR	
Bladder cancer	21		12 200	RR	
Kidney cancer	13		12 100	RR(M)	
Multiple myeloma	5		10 700	RR	
Rectal cancer	14		8500	RR	
Melanoma	17	55 000	7900	RI, MRR	
Uterus corpus	23		3200	RR	
Squamous cell carcinoma	105		2500	High Risk	
Cataract		350 000	Occurs post surgery	UV among many suspected risk factors	
Basal cell carcinoma	475 (M), 250 (F)	900 000	rare	High risk factor	

M, male; F, female; RI, incidence risk increase; RR, risk reduction; MRR, mortality risk reduction (reproduced by permission of G. Heisler).

incidence or mortality. The level of prevention seems to be proportional to the exposure to sunlight in a ‘dose–response’ relationship. That is, the higher the exposure to sunlight, the lower the incidence of prostate cancer. Each of the seven studies on breast cancer included in the review showed the positive influence of exposure to sunlight in reducing the incidence or mortality from breast cancer. The evidence for ovarian cancer was small but conclusive. This review indicates convincingly that sunlight has a preventive effect on the initiation and/or progression of different types of cancer. One explanation is that exposure to solar UV-B radiation reduces the risk of cancer through the photosynthesis production of vitamin D.

Vitamin D also affects our immune system. It is widely recognized that the active vitamin D metabolite $1{,}25(OH)_2D$ is produced not only in the kidney as previously believed but also in other tissues including colon, prostate, skin, and osteoblasts (John *et al.*, 1999; Chen and Holick, 2003; Welsh, 2004; Schwartz, 2005; Porojnicu *et al.*, 2005). The vitamin D metabolite produced outside the kidneys regulates various cellular functions in specific tissues, including cell growth, thereby boosting immunity against cancer growth.

Cancer and the melatonin hypothesis

Scientists have determined that low melatonin levels augment the incidence of cancer among rats (Blask *et al.*, 1999, 2005) and some researchers have championed the causal relationship between light and some forms of cancers through what is called the melatonin hypothesis. Melatonin is produced at night or in a light-free environment. When melatonin is suppressed, it increases the production of estrogens in the ovaries, which in turn stimulate the production of breast epithelial stem cells known to increase the likelihood of breast cancer (Cohen *et al.*, 1978).

Light exercises a major influence on melatonin and serotonin production and consequently on our circadian rhythm. Scientists speculate that the disturbance of the circadian rhythm could contribute in a major way to the cause of breast cancer (Hrushesky, 1985, 2001; Stevens, 2005). According to Reiter and colleagues (1997, 1999), melatonin can prevent DNA damage; damaged DNA can mutate and trigger the production of cancerous cells. The evidence that relates circadian rhythm disturbance and melatonin suppression to the presence of light at night (LAN) to the incidence of cancer is demonstrated in night shift workers. Approximately 8 million workers in the United States regularly work at night, and for many of these individuals (e.g., nurses, security personnel, physicians, and airline pilots) peak alertness and maximum performance are critical. In addition to performance issues, Horowitz and colleagues (2001) found that night shift nurses not only experience loss of sleep and misalignment of the circadian rhythm but also suffer greater risk of gastric and duodenal ulcers and cardiovascular diseases. The timing of their sleep–wake schedule remained permanently out of phase with the natural light/dark cycle, and resulted in health problems. Lack of sufficient sleep or sleep disorders seem to make the immune system vulnerable to attack and less able to fight off potentially cancerous cells. Another survey (Schernhammer *et al.*, 2001) showed that night shift workers are more likely to have cancer because of the LAN phenomenon, which suppresses the production of melatonin.

According to news reports, The International Agency for Research on Cancer, the cancer arm of the World Health Organization (WHO), has added overnight shift work as a probable carcinogen in December 2007. Scientists at the WHO suspect that overnight work is dangerous because it disrupts the circadian rhythm. Millions of people worldwide could be affected by this ruling because experts estimate that nearly 20% of the work force in developed countries work at night. Some day shift workers, however, also have disturbed circadian rhythm because of insufficient exposure to daylight at their workplace during the day. In September 2006, The National Institute of Environmental Health Sciences (NIEHS) convened a workshop to examine how best to conduct research on possible connections between lighting and health (Stevens, 2007). Their report outlines three major areas of future research; among them is the effect of light-induced physiologic disruption on disease occurrence and prognosis. The potential disruption of the circadian cycle, particularly at night but possibly also during the day and its contribution to the causes of cancer or other diseases is a pertinent question. The question is particularly important in part because a large and increasing segment of the population of industrialized nations is working the graveyard shift (Rajaratnam and Arendt, 2001). It is equally significant because secretion of melatonin during the night is being disturbed as a result of the population of industrialized countries reducing its exposure to darkness, as reflected in a decrease in the average duration of sleep in recent times (National Sleep Foundation 2005), and secretion of serotonin is being disturbed by insufficient exposure to daylight during the day, especially at the workplace. The combination of these two phenomena, caused by the combination of lifestyles and ill-conceived architecture, could cause circadian imbalances and serious health problems.

4.7 SUNLIGHT AND DIABETES

Diabetes is a chronic metabolism disorder characterized by hyperglycemia (high blood sugar). The World Health Organization recognizes two main forms of diabetes: type-one and type-two; and a third that can occur during pregnancy (gestational diabetes). In type-one diabetes, injection of insulin is mandatory because the beta cells of the pancreas produce no insulin, a hormone that moves the sugar from the blood to the cells. In the case of type-two diabetes, insulin may or may not be needed.

Sunlight has a direct effect on insulin secretion. Exposure to UV-B radiation has been shown to increase insulin secretion among adults (Colas *et al.*, 1988). Similarly, lower levels of blood sugar (therefore higher insulin secretion) were observed during summer (Ishii *et al.*, 2001). The Colas and Ishii studies dealt with sunlight and relationship to type-two diabetes. Other studies, however, examined the relationship between vitamin D and diabetes. The insulin-producing cells in the pancreas have vitamin D receptors and seem to function better in the presence of high vitamin D levels (Brown *et al.*, 1999). According to Chui (2004), vitamin D increases the action of insulin, which in turn increases the control of carbohydrates (sugar) in the blood. As a result, a negative correlation was found between blood sugar level and vitamin D levels.

Another study examined the effect of vitamin D supplementation on diabetic women. It showed that a daily intake of 1332 IU over a period of one month resulted in a 21.4% drop in insulin resistance and a 43.3% increase in insulin production (Borisova, 2003). It is important to note that sunlight can produce up to 20 000 IU of vitamin D per day, which can lead to enormous benefits for both type-one and type-two diabetic patients (Sorenson, 2006).

4.8 WINDOWS AND STRESS

The lack of windows in the workplace contributes to stress on the job (Heerwagen *et al.*, 1995). A recent Turkish study (Alimoglu and Donmez, 2005) investigated whether the lack of daylight in the work setting can be a predictor of job burnout of nurses who, as a group, generally have an above-average risk for work stress and burnout. Of a sample of 141 female nurses in a Turkish hospital, 46.8% reported that they were exposed to less than 3 hours of daylight during a typical work day. Using the Maslach Burnout Inventory (Maslach and Jackson, 1996) and the Work Related Strain Inventory (Revicki *et al.*, 1991) to measure burnout and stress, the study found that daylight had an indirect statistical correlation with burnout. A minimum of 3 hours of exposure to daylight seemed to reduce stress and burnout; however, the study did not specify the extent of the reduction. Roseman and Booker (1995) found that medical errors among nurses were more likely in midwinter than in the fall or summer. They reported a strong relationship between outside darkness and the rate of medical errors; however, whether the causes of such errors are psychological or are related to stress and burnout remains unclear.

4.9 HEALTH AND SPECTRAL QUALITY OF LIGHT

The spectral composition of light refers to how much of each wavelength of the visible spectrum, which ranges from 380 nm to 770 nm, a particular light source emits. Figures 4.7 and 4.8 provide a comparison of the spectral compositions of a standard 'cool white' fluorescent light source and daylight. Spectral quality is a complex term that mainly refers to how warm or cool a light appears (correlated color temperature of light, CCT) and the shift of color (Color Rendering Index, CRI) that it may cause. The CCT scale is a color-defining scale developed by William Kelvin in the late 1800s. It indicates the specific hue of a light source. The Color Rendering Index relies on a scale from 0 to 100 that represents how closely a light source depicts or reflects an object's true color. As a general rule,

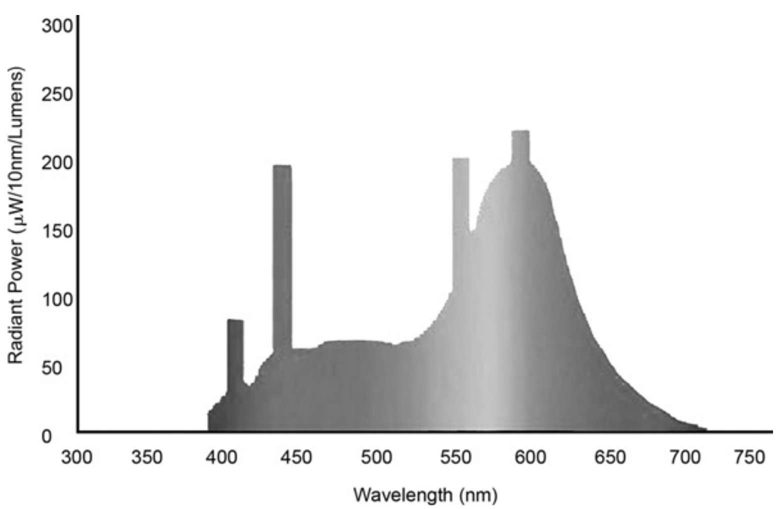

Figure 4.7 Spectral distribution of a standard 'cool white' fluorescent lamp.

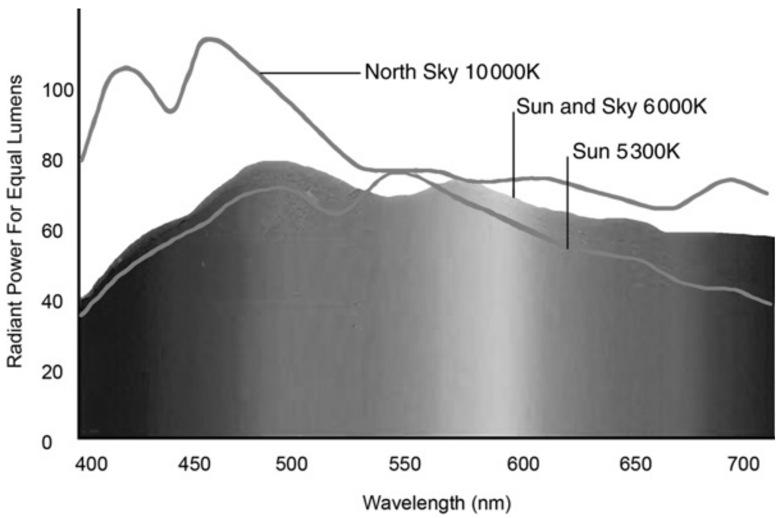

Figure 4.8 Spectral compositions of daylight.

the higher the CRI, the more accurate the color of an object will appear. Because daylight is dynamic, its color properties change. For example, a cloudy day would have a CCT ranging between 8000 and 10000 K whereas a clear northern sky at noon would have a CCT ranging from 5000 to 5500 K. In terms of its spectral composition, daylight contains 4.6% UV radiation, 46.4% visible light, and 49% infrared radiation.

The benefits of daylight in terms of its spectral qualities can best be demonstrated by the outcome of research not only on daylight but also on full spectrum lighting sources that attempt to mimic the spectral qualities of daylight. There appears to be a relationship between the spectral quality of light and the transformation of vitamin D in the skin. Bunker and Harris (1937) established that a wavelength of 297 nm is most effective in curing rickets. Knudsen and Benford (1938) found that 280 nm was the most effective in curing rickets and that wavelengths of 265, 289, 302, and 312 nm also had anti-rickets effects. Wavelengths longer than 312 nm had no effects on rickets.

Researchers in the United States Environmental Protection Agency (EPA) investigated the relative mutagenic (capable of causing mutations) effects of sunlight, fluorescent light, and typical tanning bed light on the DNA of *Salmonella typhimurium*, a laboratory bacterium often used for preliminary investigations in biomedical research (De Marini *et al.*, 1995). In this experiment researchers exposed four strains of this bacterium to sunlight, cool white fluorescent light, and tanning bed light for the same amount of time. The total radiant exposure received by each set of cultures was reported as the sum of the individual exposures to UV-A (315–400 nm), UV-B (280–315 nm), UV-C (250–280 nm) and the rest of the visible spectrum (400–800 nm). In every case, the cultures exposed to sunlight received the highest amount of radiation; however, the relative amount of UV-A and UV-B exposure varied by light type. Tanning light had a 2:1 constant ratio of UV-A to UV-B, cool white fluorescent light had a ratio of 10:1, for sunlight the ratio was 50:1.

Compared with an irradiated control group, all strains exhibited transformation of the genetic information (DNA). Tanning light, containing 80% of UV light, spurred more mutations than sunlight or cool white fluorescent light which contained no more than 10% of UV light. This experiment shows that the ability to cause mutation (mutagenicity) is strongly dependent on both the total amount of UV radiation contained in the light spectrum and the relative amount of UV-B versus UV-A within that spectrum. These results, though not conclusive, indicate that it is the nature of the light spectrum in sunlight that makes it a unique enhancement to human health. Most electric light sources do not replicate the sunlight spectrum. Furthermore, the spectral composition of sunlight changes according to the time of day and the season. This changing cycle may be the central reason for human circadian rhythms, assuming that chemical reactions to promote or inhibit alertness are initiated by UV levels contained in daylight.

Other health benefits of sunlight are found in its effect on liver metabolite, a substance produced by the liver that acts on our metabolism. Exposure to natural light stimulates the secretion of liver metabolite (Neer *et al.*, 1977), but artificially simulated daylight that mimics the spectral composition of daylight also seems to have positive health benefits. Neer's research indicated that increases in the absorption of intestinal calcium were found among healthy men kept indoors during the winter and exposed to high intensity levels of artificially simulated daylight reaching 5000 lux, a level much above that typically found in building interiors using electrical lighting.

4.10 HOW MUCH VITAMIN D IS NEEDED?

According to several sources (Sardar *et al.*, 1996; Glorieux and Feldman, 1997; Holick, 1999), the need for vitamin D photosynthesis can range from 15 minutes a day, three or four times a week, to three hours a day, three or four times a week. The length of exposure depends on the type of skin, the season, and the geographic location. Fifteen minutes of sunlight will produce enough Vitamin D to last for several days, even when the subject is wearing light clothing; however, three or more hours are required to produce enough vitamin D for dark-skinned people. Michael Holick (2004) from Boston University, author of the *UV Advantage* web-based information program (www.uvadvantage.org), estimates that we need to expose 25% of our bodies to midday solar radiation, two or thee times a week during summer to produce the amount of vitamin D deemed optimal.

In the United Kingdom, children from immigrant families are especially prone to rickets because it takes up to six times longer for dark skin to generate vitamin D than it does for white skin (Serhan *et al.*, 1999).

In Australia and New Zealand, short daily exposures of the arms, hands, and face to sunlight are recommended (Cancer Council Australia, 2005). Recommendations vary from five to seven minutes during midday periods in the summer in the sunniest northern parts of Australia to 40 minutes during the midday winter hours in New Zealand.

The World Health Organization has responsibility for defining the 'International Unit' (IU) of vitamin D. One IU of vitamin D is equal to 0.025 micrograms, which is also equivalent to 65.0 pmoles. An outside exposure of hands, arms, and face for 10 to 20 minutes three times a week produces 200 to 400 IU of vitamin D during the summer months. Estimates suggest that 100 to 200 IU of vitamin D are produced for each 5% of body surface exposed.

The vitamin D requirement for healthy adults has never been precisely defined. Since vitamin D is produced in the skin after exposure to sunlight, we do not have an additional need for vitamin D when sufficient sunlight is available; however, vitamin D does become an important nutritional factor in the absence of sunlight. Nonetheless, the current recommended dietary allowance (RDA) of vitamin D in 1989 by the Food and Nutrition Board of the Commission on Life Sciences of the National Research Council is currently 5 μg/day or 200 IU for populations up to the age of 50, 10 μg/day (400 IU) for those between the age of 51 and 70, and 15 μg/day (600 IU) for those 70 years old or older. Many researchers, however, estimate that this requirement should be much higher. Even with this possibly low RDA, most healthy individuals living in the United States are deficient in vitamin D (Fuller, 2003). Evidence suggests that the daily intake of vitamin D for people with limited exposure to sunlight should be 20–25 μg (800–1000 IU) (Glerup *et al.*, 2000). In addition, because we use vitamin D less efficiently as we age, optimum intake of vitamin D must increase with age.

The typical recommendations for optimal exposure to sunlight for vitamin D production are intended for outdoor exposure. Because glass filters out about 95% of the UV-B rays, recommendations for indoor exposure need to be about nine to ten times higher than those for outdoor exposure.

4.11 DIETARY SUPPLEMENTS

The debate about whether sunlight is more effective than dietary supplements in the production of vitamin D has been examined in two studies, one in the United States and the other in Sweden. The American study (Webb *et al.*, 1990) found that seasonal variations in serum 25(OH)D concentrations (vitamin D) caused by exposure to sunlight were highest in subjects with high mobility and declined substantially and proportionally as subjects became less mobile, irrespective of vitamin D dietary supplements. The Swedish investigation (Landin-Wilhelmsen *et al.*, 1995) confirmed these findings. The Swedish researchers concluded that although helpful, dietary supplements could not supplant entirely the effects of sunlight on vitamin D levels and that adequate measures must be taken to guarantee access to sunlight, especially for those who may be less mobile or have minimal outdoor activity.

4.12 CANCER AND URBAN DENSITY

A study that compared women living and working in London with those living outside the city, found that city-dwelling women were more likely than their rural peers to have dense breasts (Gordon, 2007). A report of cancer incidence data from 1968 to 1972 for cities of different sizes and levels of urbanization in New York state, excluding New York city, was published in the *American Journal of Epidemiology* (Nasca *et al.*, 1980). It indicated a direct association between population density and cancer incidence. A significant linear association between cancer incidence and population density was observed among males and females for cancers of the buccal cavity and pharynx, the esophagus, bronchus and lung, stomach and colon. The report noted that for carcinomas of the liver, gallbladder, pancreas, bladder, larynx, and rectum, this association was observed only among males. For malignant neoplasms of the brain and nervous system, only females demonstrated a statistically significant relationship between these two variables.

When we examine internal cancer mortality rates (Figures 4.4, 4.5 and 4.6) and consider the degree of urbanization in the United States (Figure 4.9), the markedly higher rates of

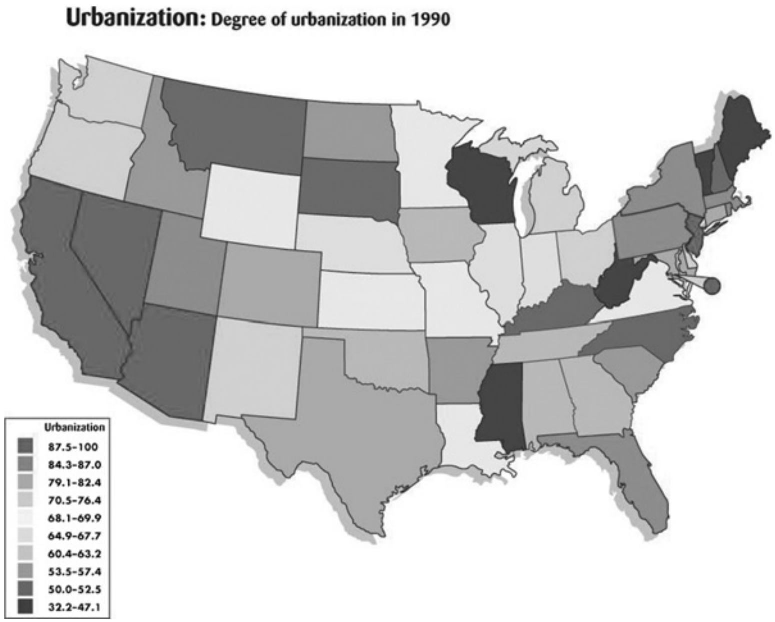

Figure 4.9 Geographical distribution of the degree of urbanization in the United States (courtesy William B. Grant).

invasive cancers in urban areas are readily apparent compared with the mortality rate in rural areas. According to Grant (2004), seven types of internal cancer were found to be inversely correlated with both solar UV-B radiation and rural residence, a finding that suggests that urban residence reduces UV-B exposure and, consequently, increases cancer incidence.

When we consider latitude and urban density and their effect on the incidence of cancer, it is reasonable to assume that the lack of sunlight, and consequently of UV radiation, is an important cause of cancer. Space planning policies and poorly designed buildings that do not allow adequate sunlight should be considered agents of ill health just as any other toxic agent.

In conclusion, and if we accept that insufficient daylight in our everyday lives disturbs our circadian rhythm, then a number of population groups are at risk for illnesses such as cancer. One population group that falls into this category includes those living and/or working in high-density urban settings. In the previous chapter we noted that light levels averaging between 2500 and 10 000 lux are needed if bright light therapy is to affect mood and overcome depression. The strong connection between mood, depression, circadian rhythm, and the hormonal balance in our bodies suggests

Figure 4.10 Light level disparity between levels found at the top of a building and those found at street level in Manhattan, New York (courtesy of Jay Davidson).

that therapeutic levels of light are necessary for healthy functioning, but these levels are neither attained inside our buildings if we rely only on electric lighting nor are they available in some populated urban centers such as New York City. Daylight levels on a street in one of the canyons in Manhattan, New York, have been as low as 1200 lux, 1/100th of the 120 000 lux measured on the roof top of an adjacent building on a clear sunny day (Figure 4.10). Of the daylight found at street level, only a small percentage (perhaps 2% or less) will penetrate adjacent buildings. Within such high density urban settings, some residents live in sub-basement apartments, others work in basement or sub-basement stores and factories, and still others may have limited mobility because of illnesses or advanced age. People in these groups may not receive adequate amounts of daylight and their health may be at risk. Furthermore, interior light levels in most buildings are usually far below levels deemed therapeutic. Because of utility costs and environmental concerns, we cannot rely on electric lighting to supply therapeutic levels of illumination.