From "Cities & Natural Process" By Michael Hough

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CLIMATE: MAKING CONNECTIONS

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In Burma once, while Bishop Prout
Was preaching on Predestination,
There came a sudden water spout
And drowned the congregation.
'O Heav'n' cried he, 'why can't you wait
Until they've handed round the plate!'[1]

INTRODUCTION

The notion that we are at the mercy of the weather is aptly illustrated in this childhood poem by Harry Graham. The interacting variable forces of wind, precipitation, temperature, humidity and solar radiation are the great climatic forces that have shaped the world's bio-regions, and to which, historically, all life forms including the human race have adapted. Indeed, it can be said that climate, more than any of the natural systems we have examined in this inquiry, transcends all the boundaries of nature and human activities. It pervades and influences water, plants, wildlife and agriculture. It is the fundamental force that shapes local and regional places and is responsible for the essential differences between them. At the same time human settlement has modified micro-climates to suit particular needs and local conditions. Human comfort, and in some cases survival, have depended on the skill with which building and place-making have been able to adapt to the climatic environment. The modern city has had a greater impact on this environment, on living conditions and attitudes, than at any other time. The old arts of creating felicitous outdoor places that take advantage of climatic elements and the material resources of the landscape seem to have been lost. As pressures for energy conservation and the need for civilizing places to live in become more urgent in the last decade of the twentieth century, we must look to environmentally sounder ways of manipulating the climate of cities than the present total reliance on technological systems. My purpose in this chapter is threefold: first, to review the nature of urban climate, and to explore how the outdoors can usefully contribute to urban liveability and conserve the city's energy; second, to bring the various components of natural and human systems into an overall framework for design – seeing the pieces of the puzzle as a whole picture; and, third, to show how the principle of connectedness, embodied in the influences of local climate, has global implications at every level.

NATURAL ELEMENTS AND CLIMATE

The basic elements of climate – solar radiation, wind precipitation, temperature, humidity – are affected and moderated by the elements of the land, including topography and landform, water and plants. At a macro-scale, landforms create barriers to the movement of air masses. They affect moisture conditions on the windward and leeward sides of hills and mountains. They affect temperatures at different heights of land – temperatures decreasing with altitude. Landforms control the flow and temperature range of air by forming impediments and channels to movement. They create katabatic valley winds that move up during the day and flow down at night, settling in valley bottoms as pools of cold air. South-facing slopes concentrate solar energy and produce different micro-environments from shaded slopes, which affects the growth and patterns of vegetation.

Vegetation controls direct solar radiation to the ground and hence the heat radiated back from ground surfaces. A forest may absorb up to 90 per cent of light falling on it and in general reduces maximum temperature variations throughout the year. It may reduce wind speeds to less than 10 per cent of unobstructed wind and maintain more equitable day and night temperatures than non-forested land. It regulates the amount and intensity of rain reaching the forest floor and affects the deposition of rain or snow and humidity. It reduces glare from reflective surfaces since leaves have a low reflective index.

Water has a profound impact on climate control. Large bodies of water absorb and store a high percentage of solar energy. They heat up and cool much more slowly than land masses and so act as moderators of temperature on land through the ventilation of onshore breezes. The process of evaporation of water converts energy from the sun into latent heat, reducing air temperatures and acting as a natural air-conditioner.

URBAN INFLUENCES ON CLIMATE

It is predicted that the energy and resource requirements of cities will, in the foreseeable future, affect not only local but regional and macro-climates.[2] Global warming, acid rain and other now familiar and much discussed issues all originate in cities. A great deal can be done to influence urban climatic conditions locally, however. To do so, we need to examine and understand the influences that affect urban climate.

It is quite apparent that the climate of cities is markedly different from rural areas. Various climatological studies have accounted for five major influences that affect urban climate, based on the fact that energy is the basis for the climatic differences between city and countryside.

- *The difference in materials in urban and non-urban environments.* The impervious surfaces of city streets and paved spaces and the stone and concrete of building surfaces, store and conduct heat much faster than soil or vegetated surfaces. In addition, urban structures are multi-faceted. Roofs, walls and streets act as multiple reflectors, absorbing heat energy and reflecting it back to other surfaces, so the entire city accepts and stores heat. It becomes, therefore, a highly efficient system for heating large quantities of air throughout its volume. In the countryside, on the other hand, heat is stored mostly in upper layers. In a wooded area the canopy receives and retains most of the heat, while lower levels remain relatively cool. City temperatures are generally warmer than the areas outside. Chandler has found over thirty years that the average temperature in London was several degrees higher than in outlying areas.[3] An illustration of the considerable contrasts in temperature regime of various materials is given by Miess. In relation to a given quantity of energy received, open water is the most constant. Between early morning and midday its increase in temperature may be no more than 3 to 4°C. By contrast, during the same period asphalt may have a temperature increase of 30°C. The temperature of grass may increase by 20°C, but at the same time its temperature drops to much lower levels at night.[4]
- *The much greater aerodynamic roughness of built-up areas than in the countryside.* The arrangement of tower blocks placed individually on their own sites presents a much rougher surface than the open country. This has the effect of slowing down prevailing winds and increasing localized gusts at street corners and around tall buildings, and diminishing the cooling power of wind in summer.
- *The prodigious amount of heat energy pumped into the city atmosphere from heating and cooling systems, factories and vehicles.* Central air-conditioning for residential buildings grew from 9 per cent of US households in 1969 to 15 per cent in 1973,[5] and the numbers have continued to grow. In winter large amounts of heat are lost to the exterior and in summer, air-conditioners cooling interior space pump hot air to the exterior, making the problem of high temperatures worse.
- *Problems resulting from precipitation.* Rain is quickly carried away by storm sewers and, in northern climates, snow is usually cleared from city streets and pedestrian areas. Evaporation converts radiated energy into latent heat, which acts as a cooling process. In the countryside, moisture either remains on the surface or immediately below it. It is thus available for evaporation and cooling. But in the city, the absence

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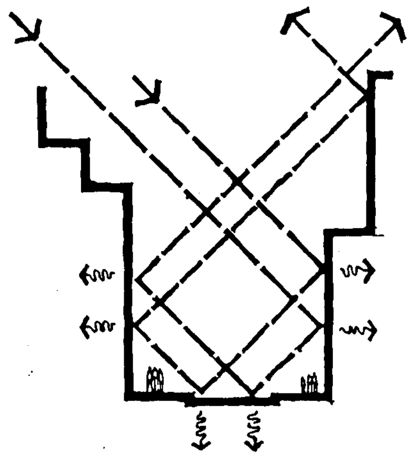


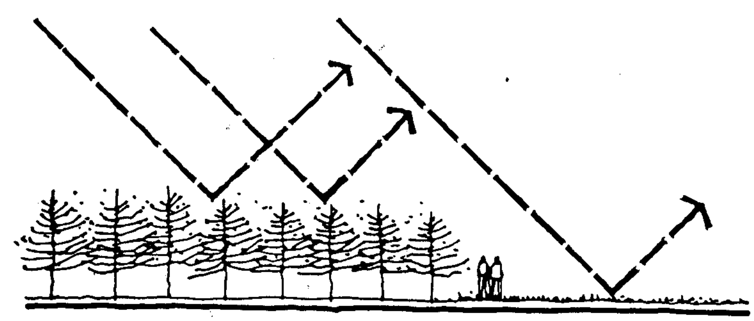
Figure 6.1 *In the city, vertical walls reflect solar radiation to the floor and walls of buildings. Impervious surfaces in walls and floors accept and store heat*

Source: *William R. Lowry, 'The Climate of Cities'*, Scientific American, *August 1967*

Figure 6.2 *In the countryside, solar radiation is reflected back to the sky due to lack of vertical impervious surfaces*

Tree canopy retains heat, while lower levels remain cool

Source: *William R. Lowry, 'The Climate of Cities'*, Scientific American, *August 1967*



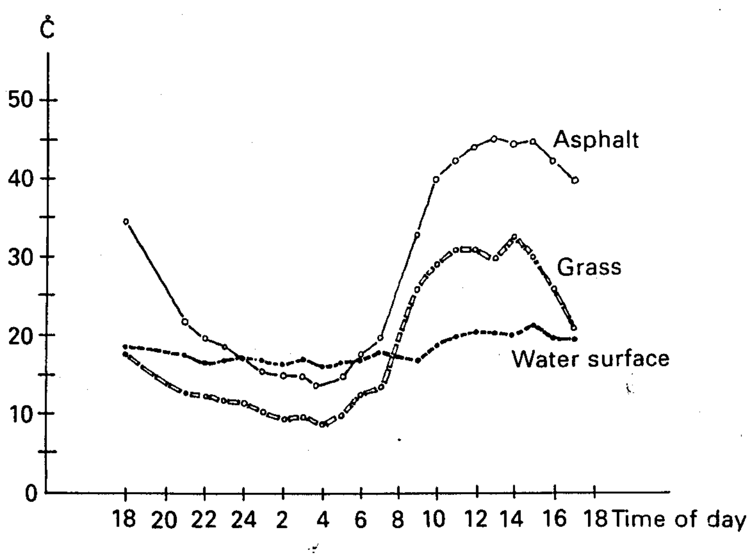


Figure 6.3 *Surface temperature of materials*

The different physical characteristics of the various surfaces exposed to radiation give rise to a very contrasting temperature regime

Source: *Michael Meiss, 'The Climate of Cities', in Ian C. Laurie (ed.),* Nature in Cities, *New York: John Wiley, 1979* of moisture inhibits evaporation. And so the energy that would have gone into the process of cooling the environment is available for heating, a decisive factor in energy exchange.[6] The capacity of building materials to store heat is greater than that of air by about 1,000 times, and the process of transfer by means of air particles into the atmosphere is much less efficient than evaporation. Only over open water and areas of vegetation does the process of evaporation become fully effective.[7]

- *Air quality.* It is estimated that the major air quality issues of the 1990s are likely to be ozone, particulates and atmospheric carbon dioxide.[8] Increased atmospheric carbon dioxide likely will lead to increased air temperatures and exacerbate ozone problems, with the major emission sources of all three being automobile and industrial processes. Ozone is formed by a photo-chemical reaction of nitrogen oxides and volatile organic compounds in ultraviolet sunlight and moisture, and affects the respiratory tissues and functions in humans. A heavy load of solid particles, gases and liquid contaminants is carried in the urban atmosphere. There are ten times more particulates in city air than in the countryside, which reflect back incoming sunlight and heat, but also retard the outflow of heat.[9] A high volume of particles in the atmosphere reduces the penetration of short-wave radiation in the ultraviolet range. This is biologically important to the production of certain vitamins and the maintenance of health. Motor vehicles are the major source of carbon monoxide in North America and can reduce the oxygen carrying capacity of blood. The higher the atmospheric concentrations of carbon monoxide the more serious the health effects.[10] Dilute sulphuric acid emissions are primarily caused by fuel combustion from stationary sources including coal. It is an irritant of the respiratory system which, when breathed in, causes bronchial constriction resulting in increased respiratory and heart rate. The consequences of air pollution on health have been found, in effect, to be serious, particularly in developing countries where air quality standards may be minimal, or non-existent. A recent study in Poland, for instance, has found new evidence linking air pollution with widespread genetic damage and birth defects. A group of organic compounds in smog caused by burning coal (a major source of energy and domestic heating in the region) called polycyclic aromatic hydrocarbons (PAH) exert a damaging effect on the genetic material in the cells of people breathing air, drinking water and eating food. A comparison between a satellite image of pollution dust in Upper Silesia and a map showing the frequency of cancer in women shows a nearly identical correlation between the two.[11]

The urban heat island

Buildings, paving, vegetation and other physical elements of the city are the active thermal connections between the atmosphere and land surfaces. Their composition and structure within the urban canopy layer, that extends from the ground to above roof level, largely determine the thermal behaviour of different parts of the city.[12] Warmer air temperatures in cities compared to surrounding rural areas are the primary characteristic of the urban heat island. This phenomenon has been studied in some detail by

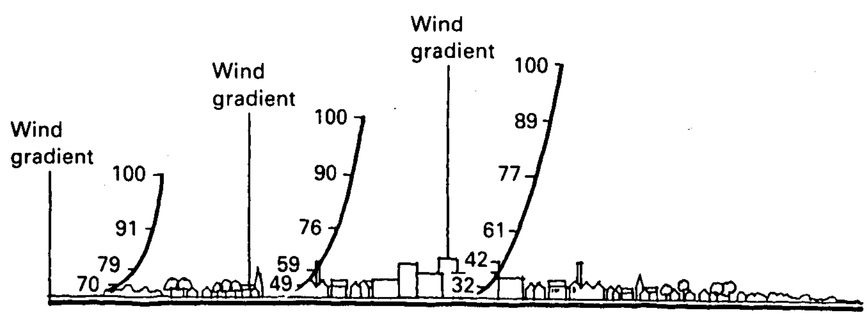


Figure 6.4 *Typical wind profiles over built-up area, urban fringe and open sea*

Increased aerodynamic roughness of built-up areas causes rapid deceleration of wind compared with open countryside. It has been calculated that wind velocity within a town is half of what it is over open water. At the town edge it is reduced by a third

Source: *Michael Meiss, 'The Climate of Cities', in Ian C. Laurie (ed.),* Nature of Cities, *New York: John Wiley, 1979*

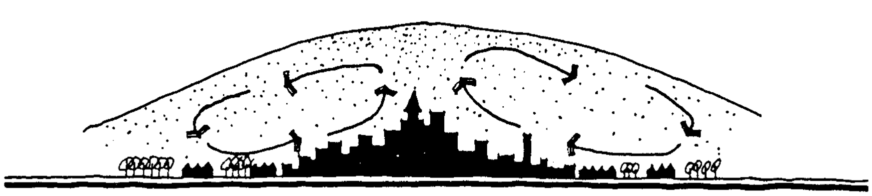


Figure 6.5 *The urban heat island*

Smog dome over large cities occurs periodically due to urban activities. Air rises over the warmer city centre and settles over cooler environs so that a circulatory system develops. The dome and its effect on city climate may persist until wind or rain disperses it

Source: *William P. Lowry, 'The Climate of Cities',* Scientific American, *August 1967*

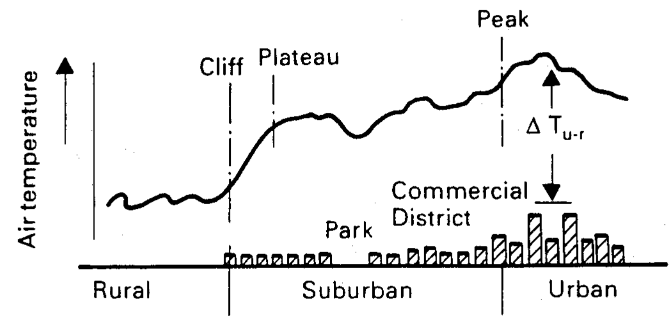


Figure 6.6 *Generalized cross-section of a typical urban heat island*

Source: *T.R. Oke*, Boundary Layer Climates, *New York: Methuen, 1987*

climatologists and is the result of the complex effects of the city's processes on its own climate. Lowry describes it as follows.[13]

Assuming a large city set in flat countryside with no large bodies of water nearby, the rising morning sun strikes the walls of its buildings, causing them to absorb heat. In the countryside, however, the sun's radiation is largely reflected off the surface with little heat absorbed. As the morning advances, the countryside begins to warm up, but the city already has a large lead towards maximum temperatures. The warm air in the city centre begins to rise and gradually a slow air circulation is established with air moving in, rising in the centre, flowing outwards at high altitudes and settling again in the open countryside as it cools. Near midday, temperatures inside and outside the city tend to equalize so that the cycle is weakened. As the afternoon passes, and the sun sinks, much of its radiation is reflected off the countryside but continues to strike building walls directly. Thus the circulation of air is repeated.

During the night the roofs and streets and other hard surfaces of the city begin to radiate heat stored during the day. A cool air layer is likely to be formed at the rooftop level. A stratification of air develops, inhibiting warmer air between buildings from moving upwards. The rural areas, however, cool rapidly at night, due to light winds and unobstructed radiation to the night sky. Although both city and countryside continue to cool during the night, by dawn the city is likely to be 4 to 5°C warmer.

The following day the heat, smoke and gases from the city are contributed to the heat being generated by radiation. The rising air also carries with it suspended particles of dust and smoke. Over time a dome-shaped layer of haze is formed over the city. At night the particles in the dome become nuclei on which moisture condenses as fog: this fog gets thicker by downward growth and eventually reaches the ground as smog. Smog inhibits cooling of the air and helps to perpetuate the dome by preventing particles from moving out of the system. In the absence of wind or heavy rain, the smog continues to build up. Since less sunshine can penetrate to warm the city in winter, increased fuel consumption adds to the smog build-up.

The process, in effect, is self-perpetuating and is responsible for the severe climatic problems that many cities face. For instance, approximately 3 to 8 per cent of the current demand for electricity for air-conditioning in the United States is used to compensate for the heat island effect because city temperatures have increased by about 1 to 2°C since 1950.[14] The effects of urban heat islands also have wider implications since urban temperatures are increasing worldwide. Comparisons of temperature data from paired urban and rural weather stations suggest that the recent warming trends are due to the heat island effect rather than changes in regional weather.[15]

PROBLEMS AND PERCEPTIONS

Mechanical climate control

The search for optimum human climates has been a continual process, particularly in those mid-latitude climates that are less extreme or predictable. Over the last two centuries remarkable changes have been made in the living environment through improvements to mechanical equipment. James Burke describes the chain of events that led to the invention of mechanical air-conditioning, by Dr John Gorrie in 1850.[16] As a physician working in Apalachicola, a small Florida cotton port situated on the Gulf of Mexico, Gorrie had been asked to report on the effects of climate on the population with a view to a possible expansion of the town. Among his recommendations was the need to establish a hospital to treat the fever that sailors and waterside workers endured every summer – an illness that was endemic to the town. Gorrie had noticed that malaria seemed to be connected with hot, humid weather. He began to solve the problem by using ice, circulating the cool air round the hospital wards by means of fans. Since ice was prohibitively expensive, he resorted to a known method for absorbing heat from surrounding gases. He constructed a steam engine to compress air, which, when cooled, rapidly expanded, and could then be circulated round a room. Subsequently, ice-making and refrigeration machines evolved from this invention and were used to transport food in ships from Australia and also for making German beer. This was followed by the domestic thermos flask and refrigerator for keeping food and drink cold. These inventions became the precursors for the modern air-conditioning unit. One of the first large installations for comfort control of office space was the 300 tonne unit installed in the New York Stock Exchange in 1904.[17] The mechanical climate control of buildings has had a number of fundamental effects on the modern city.

- It has freed buildings from the constraints of weather that were originally imposed upon it. Stylistically, modern architectural form has become an event in its own right, its design responding to the constraints of mechanical engineering rather than to the constraints of site and climate. Modern air-conditioning has permitted the development of the megastructure: great interconnected interior complexes, whose heating, cooling, humidity and daylight are entirely dependent on mechanical systems.

- It has contributed to the radical changes in urban form that have taken place since fossil fuels and other forms of energy have become abundant. The city turns its back on an outdoor environment that has become increasingly unlivable; an environment polluted by dust, smog and exhaust fumes, and alternatively swept by winter winds and cooked by summer heat.
- The preoccupation with internal climate has the effect of denying a climatic role for exterior space. Air-conditioning screens out the products of industrial processes – the chemical pollutants and dust that threaten public health. Unhealthy outdoor climates generate greater reliance on safe, controlled interior ones, and so more and more development provides interior space for urban activities. The subterranean shopping mall and links below the surface of the city is the modern alternative to the open air market.
- Its effects on lifestyles and perceptions of the environment have been profound. Urban life has become a series of air-conditioned experiences. The home, the office, the school, the bus that takes the children there, the movie theatre, have all been sealed off from the outdoors. It creates a world of its own; separated from the increasing problems of health and comfort in the world outside. It is remarkable how much energy and effort is expended to provide climatic comfort indoors, while at the same time maintaining such unrewarding environments outdoors. At one time it was even proposed that whole cities should be covered by geodesic domes: a suggestion that was seriously discussed for some cities, and which takes the problem a step further to the ultimate technological solution. One of the reasons for the lemming-like flight from the city on summer weekends is to escape from an oppressive urban climate and the air-conditioning unit for the clean air, breezes and sunshine at the summer cottage.

As I pointed out in Chapter 1, planning and design doctrine has traditionally been more concerned with conceptual ideologies of built form than with the determinants of natural process. Many early North American towns and institutions, following established planning ideologies, paid little heed to the extremes of climate in the regions in which they were located.

The effort to become independent of the variables of the environment have, by today's standards, been successful. Totally inhospitable places, from the Arctic to the Equator, can now become habitable, with mechanical heating and cooling systems providing uniform interior temperatures. But it has become abundantly clear that the present costs in energy to achieve such a goal are wasteful and, to a great extent,

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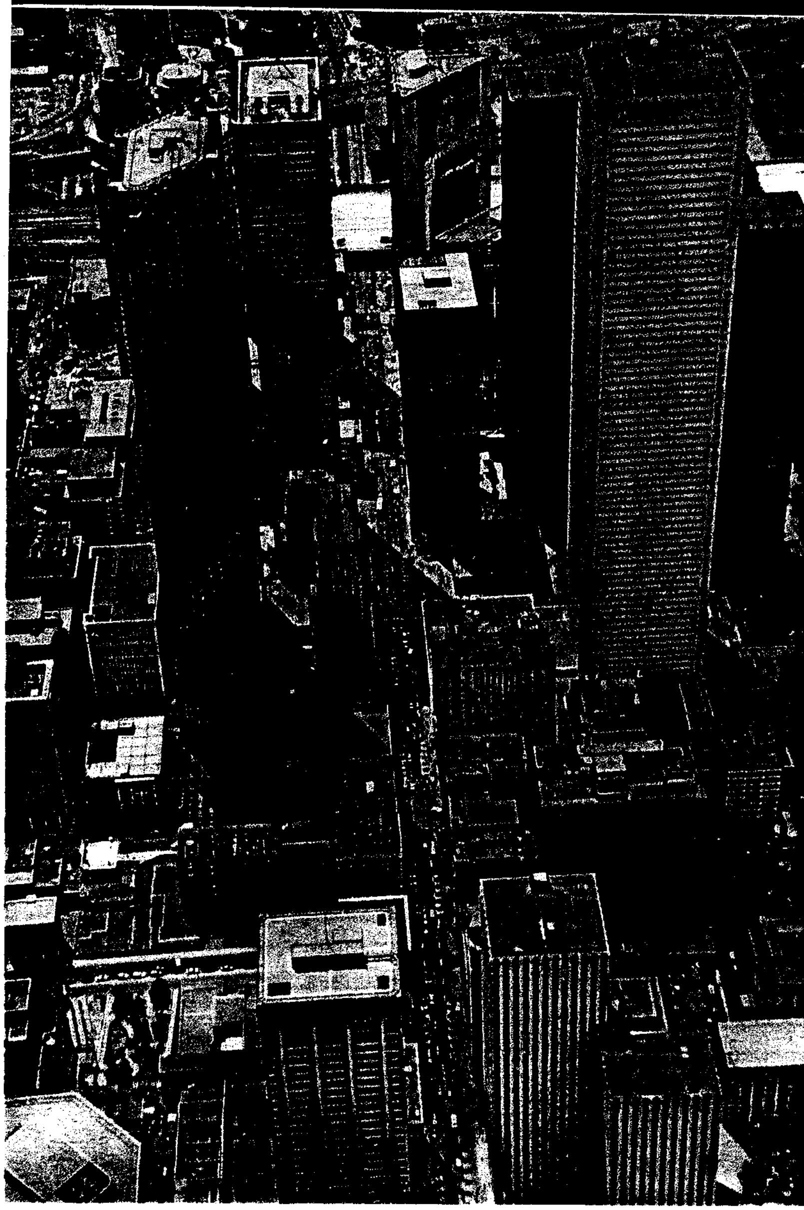
Plate 6.1 *The preoccupation with artificially controlled climate within buildings: making pleasant outdoor environments has consequently been ignored*

(Photo: Steve Frost)



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unnecessary. The air-conditioner provides evidence of this fact. The process of keeping cool inside in summer increases the already high temperature outside – a non-productive transfer of heat from one place to another. There are cheaper and more effective ways of achieving similar results. Since the outdoors comprises a large part of the city environment, it can contribute to the modification of climate. At the same time it will be apparent that some problems cannot be solved in the context of natural process alone. Air pollution, for instance, is a macro-problem requiring solutions at the source – the industries and vehicles that create it. This involves many technical and institutional issues that cross regional and national boundaries, and are beyond the scope of this inquiry. But there are positive aspects to what may be seen as an environmental problem when urbanism and nature are seen as a whole. Design, inspired by ecology and laced with a good dose of common sense, provides solutions at less cost and effort. The vernacular forms of older towns and urban landscapes are examples of adaptation that provide some inspiration and guidance for application today.

ALTERNATIVE VALUES

Macro-climate, moderated by landform, vegetation and water has, in various ways, influenced the location and nature of human settlement and uses of the land. Carter has observed that the role of the environment is determined primarily by culture rather than

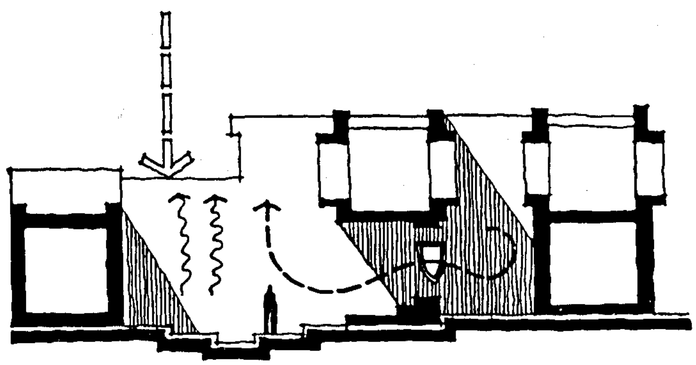

Figure 6.7 *The two courtyard house*

In this traditional Middle Eastern design, the deep, shaded courtyard is cool, the large courtyard is warm. The difference in air pressure induces a convection draught from the cool to the warm area. Water cooling jars placed in the passageway add to the cooling effect of the breeze

Source: *Allan Cain, Afshar Farroukh* et al., *'Traditional Cooling Systems in the Third World'*, Ecologist, *vol. 6, no. 2, 1976* the other way around.[18] There is no doubt, however, that humankind has responded in characteristic ways to climatic influences within its control. To be physically comfortable is a fundamental human need and a comfortable temperature lies in the range 20 to 24°C. People are affected by climate and react to it even though the response may not be conscious. There is a marked difference in the use of urban places at different seasons. On a winter's day people crowd the sunny side of the street. They seek out spaces protected from the wind; they gather where, on a hot summer's day, park seats and patches of lawn and trees provide shade or a cool breeze. The manipulation of natural and human-made elements of the environment and solar energy to create felicitous and healthy places to live and work in, has preoccupied urban people since the beginning of recorded history.

The business of keeping warm or cool in energy deficient societies is achieved by the necessity of accepting the limitations of the climatic environment and making the most of its opportunities. This has in the past, and still does in places where traditional technologies are maintained, been done with great sophistication and economy of means. The Maziara cooling jar, for instance, is a traditional water cooling and purification system, used in rural areas of Upper Egypt and other parts of the world for keeping liquids and perishable foods cool.[19] The action of evaporation absorbs considerable amounts of heat energy (580 calories of energy for every cubic centimetre of water evaporated).[20] Experiments have shown that with air temperatures ranging from 19 to

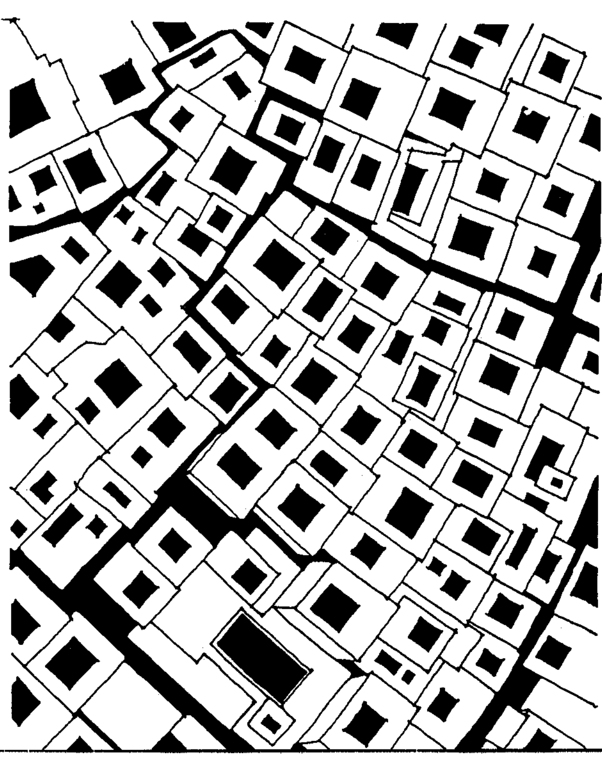

Figure 6.8 *Built form of towns in hot Mediterranean climates was often based on courtyard houses closely packed along narrow winding streets to maximize shade*

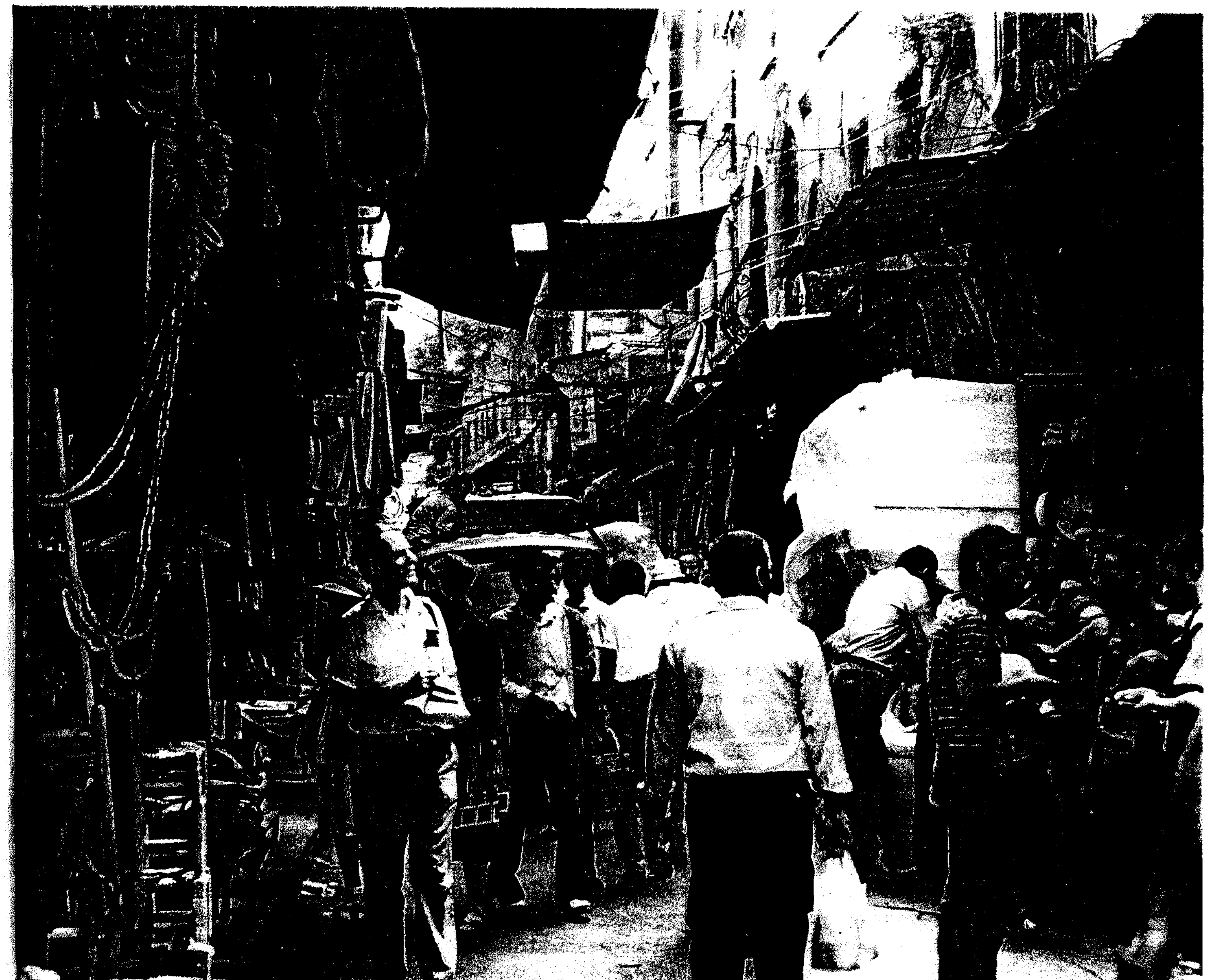

Plate 6.2 *A street in Istanbul*

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Plate 6.3 *Built form in cool climates. Closely packed buildings and streets of the pre-industrial city, built to conserve energy, trap sunlight and exclude winds. Sedbergh, Cumbria*

36°C, water temperatures in the Maziara jar remains at a constant 20°C.[21] Cities built in hot dry climates took advantage of wind for ventilation and cooling. Rudofsky illustrates a dramatic example of natural air-conditioning in the Lower Sind district of west Pakistan, where specially constructed wind scoops, installed on roofs, channelled the prevailing wind into every room.[22] Some ingenious passive cooling systems in Iran, described by Bahadori, use wind towers which operate by changing air temperatures and thus its density. The difference in density creates a draught, pulling air either up or down through the tower and through the building.[23] Courtyard houses and the agglomeration of buildings along narrow streets, typical of Middle Eastern and Mediterranean towns, maintain coolness by trapping cool night-time air and retaining it by day. Many cities in Africa and Spain use awnings or arcades to shield streets from the midday sun. Cities along the Mediterranean coast of North Africa are sited so that their streets, laid out at right angles to the shore, funnel incoming sea breezes.[24]

Plants and water have long been associated with city courtyards and gardens to provide air-conditioning and places of delight. The Moorish gardens of the Alhambra are a particularly felicitous and well-known adaptation to hot dry conditions in southern

Spain, where the evaporation of water off tiled surfaces and the dappled shade of plants cool its arcaded courtyards. Buildings in cold climates have employed techniques to conserve heat. The traditional Inuit igloo, a perfect expression of adaptation, employs the highly insulating properties of snow and orientation of entrances away from wind to create a habitable micro-climate under the harshest conditions. The hemispherical shape provides maximum volume for minimum surface area, thus minimizing heat loss. It is said to maintain temperatures of 10°C when temperatures outside are −45°C.[25] The narrow winding streets, enclosed squares, closely packed buildings and courtyards of the pre-industrial city provide as good a demonstration as any of response to climate and energy conservation. The streets minimized the effects of winds and the open squares trapped sunlight.

In all successful climate control, the siting and organization of built elements and spaces, the use of landform, plants and water have achieved optimum environments for living. Faced with climatic extremes, traditional design methods greatly enhanced urban environments because there was no alternative. Adaptations of these technologies to the modern city are equally necessary if its climatic environment is to be improved. Given the limitations of industrial pollutants, the open places of the city have an important function to perform in the restoration of the energy balance. It is to the resources and the techniques available to achieve this that we must now turn.

SOME OPPORTUNITIES

Solar radiation and heat gain

The amount of incoming radiation into a city is dependent on its layout and the pattern of its buildings, streets and open air places. Where sunlight penetrates direct to the floor, for instance in places that have large plazas and wide streets, radiation is most effectively controlled by vegetation, in particular, trees. The capacity of the forest canopy to absorb large amounts of heat energy is considerable. Short-wave radiation in a closed canopy of maple can be reduced by 80 per cent on a clear midsummer day. The forest can also reduce maximum air temperatures by about 6°C below the temperature in the open.[26] In the city the greater the closure of a tree canopy the greater will be its air-conditioning effect on surface temperatures. Surveys carried out in Germany compared a well treed square with a comparable area without trees. The daily radiation balance in June of the treed area versus the treeless one showed a difference of 256 per cent.[27] Deciduous trees have the great advantage, in climatic regions that suffer from extremes of summer and winter temperatures, of providing shade in hot seasons and permitting the sun to penetrate to the floor in winter.

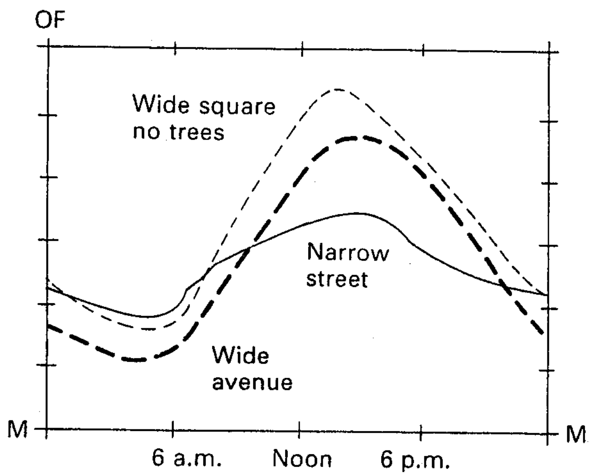

Figure 6.9 *Diurnal temperature variations in Vienna, 4–5 August 1931*

The graph shows the differences in temperature for a wide square with no trees, a wide avenue with trees and a narrow street

Source: *Gary O. Robinette,* Landscape Planning for Energy Conservation, *Reston, Va.: Environmental Design Press for the American Society of Landscape Architects Foundations, 1977*

Wall-climbing vines perform a similar function with respect to south-facing building wall surfaces. While attention may be focused on the considerable area of ground surface in cities requiring shading, it is easy to forget that vertical surfaces vastly increase the area subject to heat gain (see pp. 264–7). A German calculation indicates that there is an aggregate of some 50,000 hectares of vertical surfaces in German cities.[28] In energy terms the calculation suggests that vegetation on vertical surfaces can lower the summer temperatures of the street by as much as 5°C. Heat loss from buildings in winter can be reduced by as much as 30 per cent.[29] Biologically, the leaf is an efficient solar collector. During the summer the leaves are raised to take advantage of solar radiation, permitting air to circulate between the plant and the building. It cools, therefore, by means of a 'chimney effect', and through transpiration of the leaves. In winter, the overlapping leaves form an insulating layer of stationary air around the building. Even in climatic regions that are too cold for evergreens to grow successfully, summer cooling may still be an important factor, lending an energy-saving and biological validity to what is generally regarded as a decorative addition to architectural façades.

Rooftops in dense urban situations also receive a high level of solar radiation, paralleling the heat of ground surfaces. Rooftops constitute a large proportion of the city's upper-level environment in downtown areas and are, from taller structures, often highly visible parts of the urban landscape. Rooftop vegetation functions in the same way as it does at ground level. Rooftop gardens, therefore, can perform a functional role in climate control. The limitations to creating this kind of landscape relate to problems of structural support for soil and plants which, while they can be overcome in new projects, may constitute major problems for the large areas of existing roof areas in the city. There

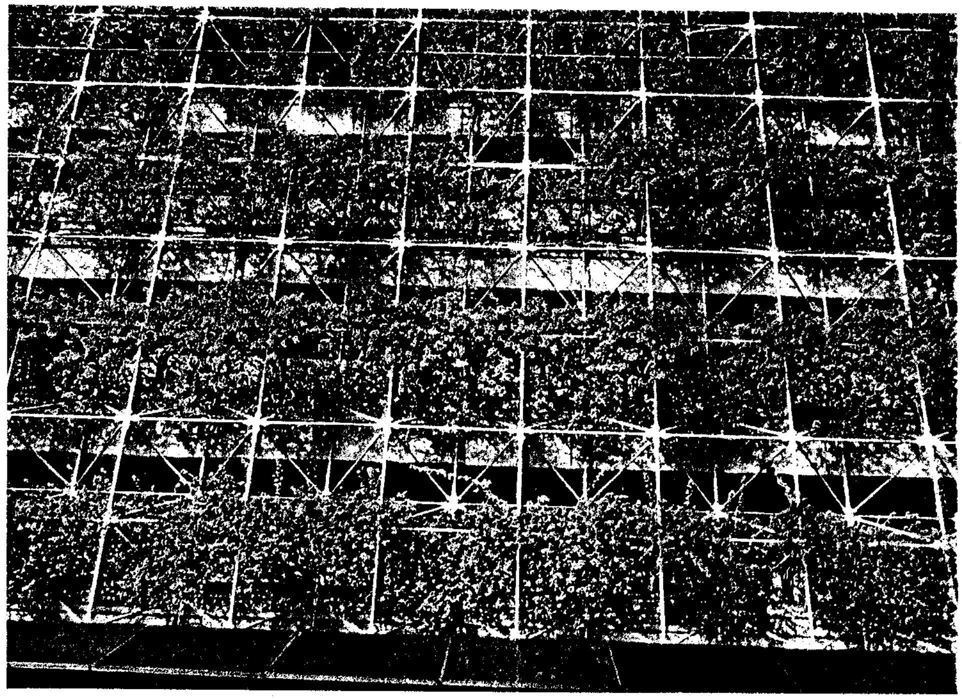

Plate 6.4 *Plants covering building walls do more than look nice. In hot climates they can reduce city temperatures by as much as 5°C: a parking garage in Jakarta, Indonesia*

are also severe drainage, irrigation, nutrient and (in cold climates) frost problems to be overcome. Alternative strategies must, therefore, be found to combat one of the major climatic and visual problems of many urban areas. An examination of many old rooftops will reveal that fortuitous plant communities often gain a foothold. Mosses, grasses and, in places where a small amount of humus and water can collect over time, even adventitious shrubs and small trees colonize these unattended and forgotten places. The issues of fortuitous plant communities have been discussed in detail in Chapter 3 (pp. 101–6), but it is relevant here to pursue their role in climate amelioration. A research programme undertaken by the Parks Department in Berne, Switzerland, on a concrete garage roof, showed that certain plants can be grown on 7 cm of soil consisting of pea gravel and silt sand. Various sedum species were used and became well established after a year. Other experiments using grasses and climbers such as Virginia creeper (*Parthenocissus quinquefolia*) have shown that many vigorous plants can adapt to such environments with minimum soil depth or humus content.[30] The city of Dusseldorf, Germany, has regulations requiring large flat-roofed areas to have roof gardens. These and other examples in Europe suggest that hardy plants adapted to city conditions can survive in hostile environments at very little cost and without adding to the weight of existing or new building structures, and that the creation of a new and economical landscape at roof level can contribute to the climatic conditions of the city by reducing heat absorption.

Temperature controls

City temperatures are related to solar radiation and heat gain from urban materials. Temperatures are generally higher than in the countryside. This is accounted for by reduced evaporation, greater conductivity and heat storage capacity of building materials, variations in wind around buildings and the high proportion of airborne pollutants. Temperature can be controlled in several ways.

Water

One of the most effective ways of controlling local climate is through the evaporation of water into the air, particularly in dry climates. This is achieved in several ways: by direct evaporation from open water and by the evapotranspiration of plants. The high run-off coefficients of paved surfaces and the efficient removal of surface water by storm sewers, have effectively removed its availability for evaporation and cooling. This function is greatly assisted by reintroducing water into the city. It occurs by design where pools, fountains or artificial lakes are reintroduced into the city landscape. But it also occurs fortuitously after rainstorms where water forms ponds in parking lots, low-lying turfed areas and other 'poorly designed' places, where it becomes freely available for evaporation. Surface water introduced into the city's paved and unpaved places by impounding rainwater serves an important climatic function, as well as restoring hydrological balance, and providing recreation, wildlife and aesthetic enhancement. There are also pollution and erosion control advantages in doing so that have been discussed in more detail in Chapter 3 (pp. 126–8).

Plants

Plants evaporate water through the metabolic process of evapotranspiration. The cycle of water is carried from the soil through the plant and is evaporated from the leaves as a part of the process of photosynthesis. It has been estimated that on a single day in summer, 0.4 hectares of turf will lose about 10,800 litres of water by transpiration and evaporation.[31] The transpiration of water by plants helps to control and regulate humidity and temperature. A single large tree can transpire 450 litres of water a day. This is equivalent to 230,000 K calories of energy in evaporation which is rendered unavailable to heat surfaces or raise air temperatures.[32] Federer has compared the effectiveness of this evaporation by a tree to air-conditioning. The mechanical equivalent to the tree transpiring 450 litres a day is five average room air-conditioners, each at 2,500 K calories per hour, running 19 hours a day.[33] He also points out the important fact that the air-conditioner only shifts heat from indoors to outdoors and also uses electric power. The heat is, therefore, still available to increase air temperatures. But with the tree, transpiration renders it unavailable.

It will be obvious, therefore, that in energy terms a tree shading a house is more effective. It produces no unwanted waste products from the process of cooling, uses no electric power and continues to work better and better over the life of the tree. A numerical simulation of urban climate has suggested that where at least 20 per cent of an urban area in mid-latitudes is covered by plants, more incoming solar radiation is used to evaporate water than to warm the air.[34] These facts are borne out in Davis, California, where temperatures can reach 38°C. Various studies have shown that neighbourhoods with shaded narrow streets can be as much as 6°C cooler than those with unshaded streets. Moreover, a neighbourhood that is 6°C cooler uses only one-half the amount of electricity for air-conditioning than an unshaded neighbourhood.[35] Based on these findings, in 1977 Davis City Council unanimously passed an ordinance requiring a minimum of 10 per cent of a paved parking lot to be canopied by trees within fifteen years of the building permit's issuance.[36]

Climatic factors also determine management objectives. The ability of trees to act as sponges of carbon dioxide in the face of increasing concern and debate over global warming has greatly enhanced the attractiveness of urban tree planting. Analysis of the urban forest in Oakland, California, reveals it currently stores approximately 145,000 tonnes of carbon.[37] Future growth and planting of trees can add to that storage total if the amount of carbon sequestered due to growth and planting remains greater than the amount of carbon lost due to mortality. In addition, it has been calculated that large-scale planting and the use of light-coloured surfaces in cities have the potential to conserve about 2 per cent of the total production of carbon in the US.[38] The landscape value of trees in raising housing values or in making light industrial areas more saleable is also a significant factor.[39]

Wind

Of all the influences the city has on weather it is the presence or the absence of wind that has the greatest impact on the comfort of the local climate, as anyone who has walked the streets of a Canadian mid-western prairie city in winter will agree. There is less wind on average in cities than in the open countryside. Meiss states that within a town, wind velocity may be half of what it is over open water.[40] On the other hand, the existence of

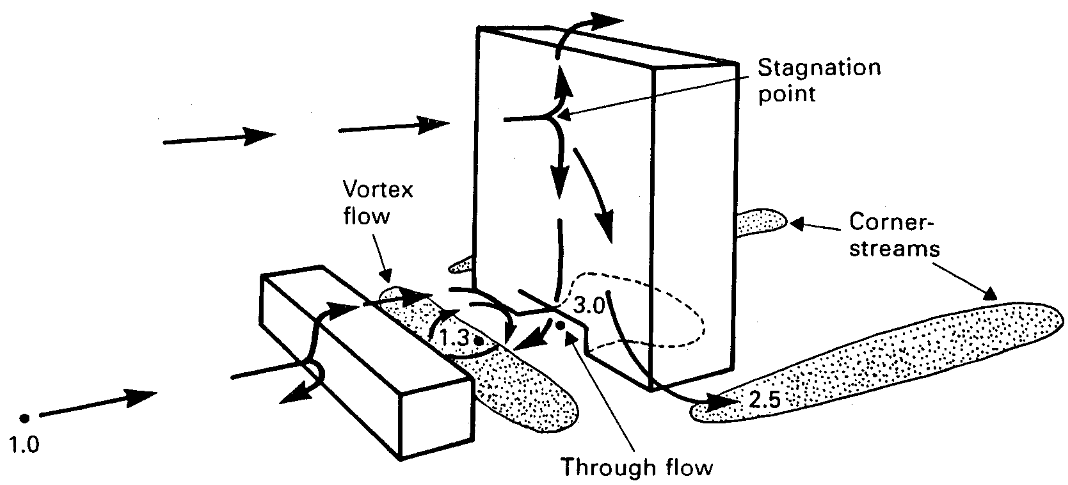

Figure 6.10 ***Air flow in the vicinity of a tall building with smaller buildings upwind***

The stippled areas show areas of considerably increased wind speed at pedestrian level

Source: *T.R. Oke, 'The Significance of the Atmosphere in Planning Human Settlements'. In E.B. Wiken and G. Ironside (eds).* Ecological (Bio-physical) Land Classification in Urban Areas. *Ecological Land Classification Series, no. 3, Ottawa:, Environment Canada, 1977. Modified after Penwarden and Wise 1975*

free-standing towers separated by large open areas and the general layout of streets speed up winds locally, creating the unpleasant gusty windswept conditions and drifting snow which are typical of a winter's day. Wind affects temperatures, evaporation, the rate of moisture loss and transpiration from vegetation and drifting snow; all of which are particularly important to local micro-climatic conditions.

The impact of the wind environment around tall building complexes that have become typical of many suburban development projects is well known. The generally uniform low building layout of older towns, arranged along curved streets, provides shelter – the result of lower wind gradients at ground level. When winds meet a building that is considerably taller than its neighbours, the flow patterns changes. Air currents divide at about two-thirds or three-quarters of the building height, creating a down draught on the windward face, and highly turbulent conditions at ground level. Reduced air pressure on the lee side creates suction and high wind speeds around corners and through passageways under the building. Oke has found that since the force exerted by the wind increases as the square of its speed, a threefold increase of speed is associated with a ninefold increase in force; sufficient to knock down passing pedestrians.[41]

Many other studies on the effects of forest cover and shelter belts on winds have been made with respect to the speed of air movement, the protection afforded and the effect of wind barriers on heat loss from buildings. Tree stands are effective in slowing wind;

the greater the roughness of the ground surface the more wind velocities are reduced. The smaller an open forest clearing, the less turbulence at ground level there will be. Shelter belts may reduce winds by 50 per cent, the sharpest reduction in wind velocities extending ten to fifteen times the height of the trees on the lee side.[42] According to Olgay, a 32 k.p.h. wind can double the heat load of a house normally exposed to 8 k.p.h. winds.[43] The agricultural experiment station at Kansas State University has shown that the heating load on a house can be greatly reduced with the use of wind breaks.[44] Measurements of the effect of wind-break planting around unprotected residential buildings indicate that annual heating costs can be reduced by 10 to 30 per cent.[45] The Ontario Ministry of Housing has also calculated that landscaping around residential buildings in the temperate climate of southern Ontario is capable of producing energy savings in excess of 5 per cent.[46]

Air pollution control

As I mentioned earlier, the only satisfactory controls for the solid particles, gases and other airborne contaminants carried in the city's air are institutional and technical. Much improved air-conditions have been achieved in Great Britain due to tight air pollution control laws and regulations. At the same time it is evident that a return to the use of coal would again aggravate the air pollution problem. There is also little doubt that air pollution from vehicular emissions will continue to exist for many years as a reality of urban climate.

Where air pollution is dilute, however, an important environmental control device is plants. It has long been known that plants filter dust in cities. Ongoing research in plant physiology suggests that they do more than act as filters. The surface area of a tree has evolved to maximize light and gas exchange. Trees have ten times the surface area of the soil on which they stand. A hundred-year-old beech, for instance, has been estimated to have some 800,000 leaves, and a leaf surface area of 16,000 square metres per 160 square metres of tree base. Calculations show that the intercellular spaces of leaves (the sum of cell walls) increase the total leaf area to roughly 160,000 square metres.[47] Leaves can take up or absorb pollutants such as ozone and sulphur dioxide to significant levels. Urban vegetation can mitigate ozone pollution by lowering city temperatures and directly absorbing the gas.[48] It has been demonstrated that a Douglas fir with a diameter of 38 centimetres can remove 19.7 kilograms of sulphur dioxide per year without injury from an atmospheric concentration of 0.25 parts per million (p.p.m.). By way of illustration of the effectiveness of trees in removing sulphur dioxide, it shows that to take up the 462,000 tonnes of sulphur dioxide released annually in St Louis, Missouri, it would require 50 million trees. These would occupy about 5 per cent of the city's land area.[49]

Measurements taken in 1962 in Hyde Park in London, indicated that the concentrations of sulphur dioxide were reduced, partly because of the local circulation of air generated by the vegetation, and partly because of the uptake of gas by the leaves.[50]

Soil micro-organisms are more effective than vegetation in removing carbon monoxide and assist in the conversion of carbon monoxide to carbon dioxide. It is believed that oxygen released by roadside plants may help in lowering carbon monoxide levels along heavy traffic routes. Nitrogen oxide combined with gases such as oxygen produces nitrogen dioxide, which is then readily absorbed by vegetation.[51]

Vegetation also collects heavy metals. In New Haven, Connecticut, one researcher found that a sugar maple 30 centimetres in diameter removed 60 milligrams (mg) of cadmium and 140 mg of lead from the atmosphere during one growing season.[52] This suggests that vegetated spaces can provide areas where dust can settle out and where air pollutants are diluted. However, it is evident that plant damage occurs when pollutants are excessive. Schmid points out that the severity of plant damage is complicated by many factors, such as the age of the plant, its state of nutrition, moisture when exposed and other factors.[53] Plant species also vary in their tolerance to air pollution and their effectiveness in improving air quality. In effect, plants cannot be regarded as the panacea for ameliorating air pollution problems, but they do assist air purity and serve one other important climatic function – as indicators of air pollution and thus of the health of the people who live in cities. There are, therefore, highly valid reasons for the reforestation of urban areas in the planning and design of the urban environment.

Energy

While the larger issues of air quality control are beyond the scope of this inquiry, it is now conventional wisdom that a major threat to human, and non-human health in cities derives from vehicular emissions. An analysis of the energy efficiencies of various transportation options in terms of the amount of energy used in British Thermal Units (BTUs) to transport a passenger 1.6 kilometres in Canada demonstrates that the more efficient freight transportation modes are the most frequently used. However, in passenger transportation, the most heavily used mode – the car – is the least energy efficient. This is true for both urban and inter-city transportation.[54] A report on the future of urbanization by the Worldwatch Institute has shown that inner-city residents of New York use only one-third of the gasoline of residents living in the outer regions of the tri-state metropolitan area of New York, New Jersey and Connecticut; Manhattan residents use on average only 400 litres of gasoline per capita each year, a consumption level close to European cities.[55] The relationship between gasoline consumption and urban density in major cities around the world is illustrated in Table 6.1 and clearly

Table 6.1 *Urban density and gasoline consumption in major cities, 1980*

City	*Gasoline consumption per person (megajoules)*	*Overall population density (People per hectare)*	*Inter-city population density (People per hectare)*	*Overall job density (Jobs per hectare)*	*Inner-city job density (Jobs per hectare)*	*Private automobile travel (per person, kilometres)*
American cities[1]	58,541	14	45	7	30	12,507
San Francisco	55,365	16	59	8	48	13,200
Chicago	48,246	18	54	8	26	11,122
Australian cities[1]	29,849	14	24	6	27	10,680
Melbourne	29,104	16	29	6	40	10,128
Sydney	27,986	18	39	8	39	9,450
Metro Toronto	34,813	40	57	20	38	9,850
European cities[1]	13,280	54	91	31	79	5,595
Frankfurt	16,093	54	63	43	74	6,810
Stockholm	15,574	51	58	34	62	6,570
Paris	14,091	48	106	22	60	4,199
Asian cities[1]	5,493	160	464	71	296	1,799

Notes: 1 The figures given for American, Australian, European and Asian cities in the table are average for the cities in those regions studied by Newman and Kenworthy. The data reflect results from ten American, five Australian and twelve European cities. The Asian data are for the three 'westernized' Asian cities of Tokyo, Singapore and Hong Kong

2 *Interpretation:* The extent to which people choose to use private passenger cars is a direct function of urban density. Cities which are more compact are significantly less dependent on automobiles. Residents of US cities drive their cars, on average, two to three times as far as do residents of European cities. Toronto is about mid-way between a typical American and a typical European city in this regard

Source: Robert Paehlke, 'The Environmental Effects of Intensification', prepared for Municipal Planning Policy Branch, Ministry of Municipal Affairs, 1991. Based on Canadian Urban Institute, *Housing Intensification: Policies, Constraints and Challenges*, Toronto: Canadian Urban Institute, 1990, p. 13. Compiled from material originally presented in Peter Newman and Jeffrey Kenworthy, *Cities and Automobile Dependence: An International Sourcebook*, Hampshire: Gower Publishing, 1989

demonstrates the implications of current urban form on energy use. For instance, Houston, Texas, with approximately eight persons per hectare uses four and a half times as much gasoline as Copenhagen with a density of thirty persons per hectare. And at the extreme end of the scale, Houston's gasoline consumption is over five times that of Hong Kong with 300 persons per hectare.[56]

Thus gasoline consumption and air quality are essentially linked to urban form in the low-density suburban and fringe areas of the city, and reinforce the dominant role of the automobile in western society.[57] It also has radical implications for such issues as the consumption of agricultural land, damage to habitat, biological diversity and depletion

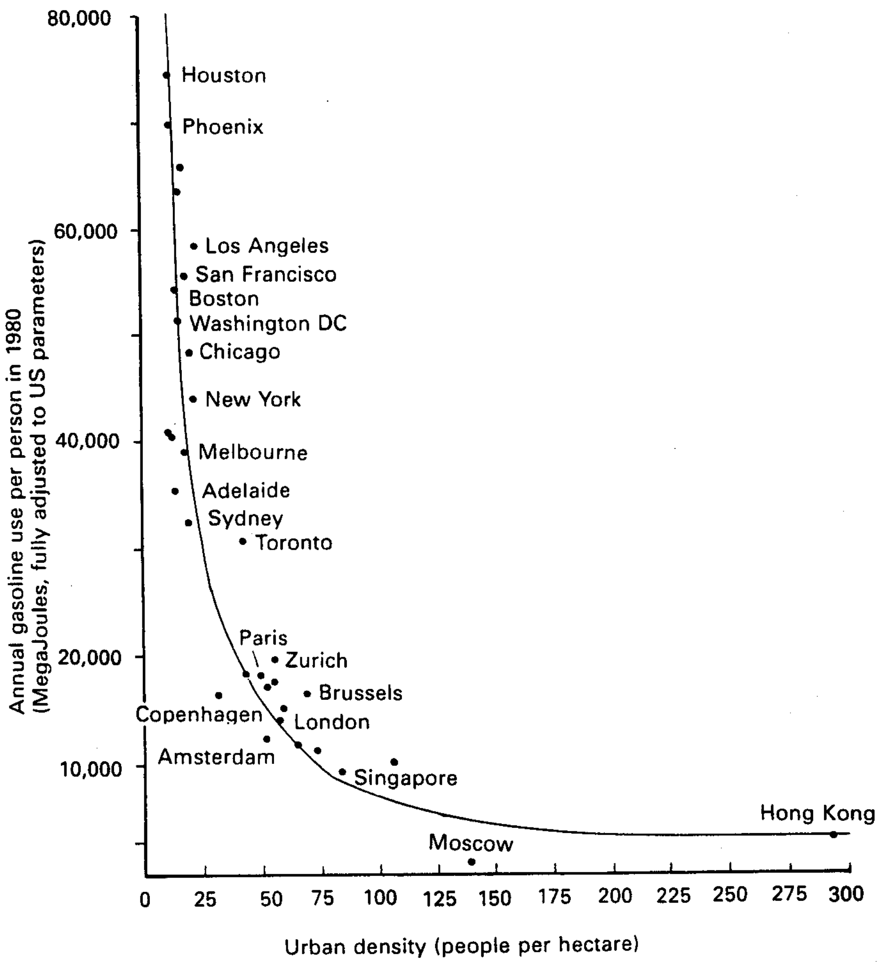

Figure 6.11 *Gasoline consumption and urban densities in major world cities, 1980*

The relationship between increasing densities and reducing energy consumption is clearly evident

Note: *Figures for all cities have been adjusted to US income, vehicle efficiency and gasoline prices*

Source: *Robert Paehlke, 'The Environmental Effects of Intensification', prepared for Municipal Planning Policy Branch, Ministry of Municipal Affairs, 1991, after Peter Newman and Jeffrey Kenworthy,* Cities and Automobile Dependence: An International Sourcebook, *Hampshire: Gower Publishing, 1989*

of non-renewable energy sources, and the need for producing alternative and more compact urban development patterns. One way of resolving these issues is illustrated by the case of Davis, California, discussed on pp. 262–3 and 279–83.

IMPLICATIONS FOR DESIGN

Green lungs

We have found that water and plants are the important natural elements of climate amelioration in the city. But what is their sphere of influence? How much vegetation or surface area of water is needed to have a marked effect on the climate of the city? Where should they be located? Answers to these questions depend on the climate of the region, the nature and variations of climate between one place an another, the characteristics of the site, its topography and the nature of the built-up area. At a small scale, experience tells us that a sheltered, well treed environment is a cooler and more pleasant place on a hot day. The sphere of influence of its elements – tree canopy, shrubs and water – would appear to be local, however, particularly if it is an isolated place in the general fabric of streets and buildings. The walled gardens of old European towns create a sphere of influence within them that are considerably cooler, or warmer, than outside. The impact of major spaces, the so-called 'green lungs' of the city, that have long been the ideal of landscape planning, may well be limited in the overall urban climate. Jane Jacobs has observed that the term 'green lung' is only applicable to the park spaces themselves and has little effect on the overall quality of the air in the city.[58] There have been claims that the oxygen produced by vegetation can affect the balance of oxygen in the air. These have evolved from the fact that much more oxygen is produced in photosynthesis than is used up in respiration. There is, however, as much oxygen used up in plant decay and the metabolism of animals that feed on plants as there is released by photosynthesis. The concept of the 'green lung' may be inaccurate in describing the effect of parks on the oxygen content of the city overall, but research has established definite connections between forest vegetation cover, open space distribution and urban climate control.

Meiss observes that the necessary amount of open space in an urban area and its optimum distribution cannot be stated quantitatively.[59] But from a climatic point of view, a fine mesh of small spaces, distributed evenly over the whole city, is more effective that reliance on a few large ones. These latter spaces need to be supplemented by a large number of small parks throughout the built-up area. 'Such a mesh facilitates horizontal exchange of air bodies of varying temperatures and consequently a balance is reached more quickly and with less resistance.'[60] A study of Dallas and Fort Worth found that the heat island reached its peak not in central areas of tall buildings, but along the fringes of the downtown area that contained low buildings and parking lots.[61] This suggests that efforts to ameliorate climate should be concentrated in these areas. Bernatzky suggests that the effect of the heat island can be partially counteracted by concentric rings of vegetated space to filter and oxygenate the air as it moves inward to the city centre.[62] In summer the heat from increasing densities in the city centre heats air which rises, creating a low air pressure area. This in turn draws cooler air in from the edges of the city. The quality of the air as it moves into the city is increasingly degraded, accumulating gases and particulate matter and being progressively de-oxygenated. Parks and vegetated spaces located in the path of this moving air will alter wind flow, ameliorate air quality and reduce temperature. In Chicago, air flow modelling has concluded that a finger plan with corridors of development and wedges of open space would have the most positive effect on air quality.[63]

Some design principles

There is still much to be learned about the effects of these natural processes on the city-wide climate, and how the scientific data that have been accumulated may be applied in determining optimum patterns of open space. Researchers in the field have varying views on what those patterns might be. We must, however, be careful to avoid the trap that often awaits those seeking answers to such problems – the temptation to create cookie-pattern solutions for every urban situation. This, in fact, is precisely the criticism that has been levelled at many planning theories in the past that have attempted to seek standard solutions for the cities. They ignore the inherent individuality and uniqueness of each place and, therefore, of each city. Thus, while there can be no final or definitive solution to the questions that have been explored here, certain general principles do emerge that are both pertinent and useful to this inquiry.

- The natural patterns of the land, its mountains, hills and valleys, its rivers, streams, open water, forest and grassland, determine local climatic patterns and affect, in some measure, the environment of the city. Although the extent of this influence may be local, the retention and enhancement of natural features for climatic reasons, are essential parts of the design process. An example of where climatic patterns, conditioned by topography and vegetation, have had a major impact on city form is the case of Stuttgart, Germany, described on pp. 278–81.
- Vegetation and water have a major effect on the maintenance of an equable micro-climate within cities. Since the large areas of paved and hard surfaces in the city generate the greatest heat in summer, establishing canopy vegetation wherever possible will reduce the adverse effects of the urban heat island. It will also remove dust and purify toxic gases and other chemicals. Dense canopies that provide maximum shade are much more effective than current practice, which sees trees as individual specimens. In addition to micro-climatic benefits, the continuity of the tree canopy also provides connected environments for some species of wildlife. In South Africa many parking areas are shaded by canvas canopies, to protect vehicles from

the summer sun, and also as a protection against frequent and damaging hailstorms. The retention of water and natural ponds in parks and other locations is also critical to restoring the energy balance by direct evaporation, and they serve many other hydrological and wildlife functions which have discussed in previous chapters.

- The large roofscape areas of downtown and suburban industrial sites contribute to heat build-up. The development of rooftop planting serves a similarly important role in climate amelioration. There is a need for basic practical research into lightweight low-maintenance techniques for establishing plants on existing rooftops, similar to the work in Germany described on p. 261. The use of naturalized urban vegetation that can survive with little or no care, and under the most severe conditions, has important implications for climate control.
- In most successful examples of climate manipulation in extreme conditions, the emphasis has been on an urban texture of small spaces and low buildings. In hot summer climates, narrow streets and small living spaces increase shade and reduce the build-up of solar radiation. They are, in addition, easier to control artificially through the use of orientation, shaded canopies, arcades, plants, water and ventilation. In cooler climates they are less subject to cold winds, drifting snow and extremes of temperature. Organization of space can create suntraps by orienting buildings to the south and excluding winter winds. In most cities where built form has evolved with little regard for climatic considerations, the materials of the landscape, as well as new built form, must serve a climatic role. Plants, groundform and building canopies, must be used to create suntraps and sheltered places, to counteract prevailing winds, modify down draught and so on.

The response to urban climate is the first step in the establishment of a vernacular; of a regional character that links built form with the place in which it occurs. Without this response, the designed landscape may be as clearly identified with the now defunct International Style as was the architectural style that gave rise to the name, but which none the less continues under different titles. Several contemporary examples of form evolving from climatic determinants are illustrated in the following pages.

Example 1 A northern university

In the late 1960s and early 1970s the University of Alberta underwent a major expansion programme to accommodate almost a doubling of its student population. Located within the city of Edmonton, Alberta, the university is very much a part of an urban environment that had one of the fastest growth rates in Canada. One of the most critical objectives of the development plan was to create an appropriate campus environment for

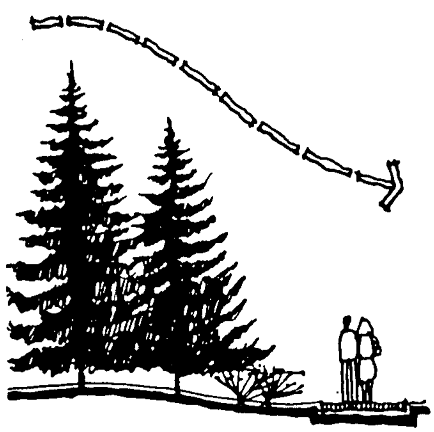

Figure 6.15 *Walkways protected by windbreaks in large open areas*

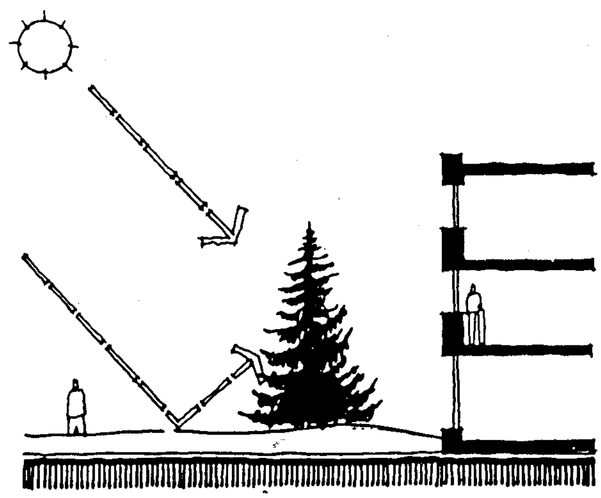

Figure 6.16 *Snow glare and intense light from low sun may be reduced by the use of coniferous or dense deciduous plants*

Example 2 Climate and city form

The links between major landforms, vegetation and urban form are nowhere better seen than in the city of Stuttgart. Located in the centre of an industrial region or over 2 million people, the city was plagued by air pollution from industrial stacks, cars and the use of coal and oil for heating dwellings, a situation greatly accentuated by frequent temperature inversions due to its location. The city occupies two valleys lying at right angles to each other. The main part of the city is situated in a basin-like valley (the Nesenbach), which is surrounded on three sides by steep slopes which extend on ridges into the centre of the city. The remainder is located along the open valley of the Neckar. The pollution problem became worse when urban expansion started to occupy the valley sides, replacing vineyards and forests with buildings. These buildings interrupted the normal katabatic flows of air, associated with valley land formations, from the surrounding vegetated hills to the city which had originally acted to minimize air inversions. It became apparent that there were interrelated links between open space distribution, climatic phenomena generated by topography and wind flows and a healthy city environment.

The prohibition of coal and oil for home heating was included in 150 local plans in the Stuttgart region and replaced with natural gas, reducing sulphur dioxide emissions by over 100 tonnes per year.[66] A network of parks was established in the city, linked to each other, to the river, forests and vineyards on the valley slopes. The forests, productive commercial resources, the vineyards and other arable lands account for about two-thirds of the total municipal area of 20,723 hectares.[67] Climatically, the vineyards tend to be more efficient than recreational lands since the vertical rows of vines permit uninterrupted air flow down valley sides. The function and character of the city's spaces is highly varied. Stuttgart's natural topography is such that the city's central parks are flat and those further out are located on steep valley sides that provide breezes down wooded slopes and a dramatic setting within the urban area. Within the parks themselves (which cover some 490 hectares), the use of plants, lakes and water sculpture has been exploited to provide places full of refreshing and varied sights and sounds. Green spaces are on the average 3°C cooler than surrounding built-up areas.[68] On both a city-wide and human scale, the parks and working landscapes within and surrounding Stuttgart are among the most climatically functional, socially useful and aesthetically pleasing of any modern city in the western world. From a landscape planning perspective their influence on its climate is matched by their function as 'green infrastructure', giving form and identity to the city.

Example 3 Energy conservation policies: Davis, California

Davis, California, is a city that has become internationally recognized for its integrated approach to energy conservation, one that has linked energy-efficient building, community design (including street and lot layout, landscape design and city-wide landscape planning), transportation, wildlife habitat, recycling of materials, water conservation, gardening and neighbourhood social life.

Davis' energy-conscious general plan was adopted in the early 1970s. It was the result of intensive background technical research by a number of working committees, and widespread public involvement. This in turn led to the development of the final Energy Conservation Code in 1975, unanimously adopted by the City Council the same year.[69] Climatic studies carried out on the thermal performance of buildings found that some buildings became dangerously hot due to direct solar heat gains through large east- or west-facing windows, while identical buildings with north- or south-facing windows remained comfortably cool and used substantially less energy for cooling. Similarly, south-facing windows exposed to the winter sun were significantly warmer during the winter – over 6°C on cold sunny days.[70] As part of this study the Davis climate was examined in light of the needs for energy conservation. Daytime maximum temperatures during July, the hottest time of the year, average 36°C. The night-time minimum, however, averages 13°C, a phenomenon caused by thermally induced sea breezes

Figure 6.17 *View of Stuttgart from forested slopes*

Figure 6.18 *Connections link park system together*

Figure 6.19 *Water forms a major element in the parks*

Figure 6.20 *Plants and shade over paved surfaces are distributed everywhere in Stuttgart*

[redacted]

originating over the Pacific Ocean and flowing into portions of the Central Valley. These findings led to the adoption of minimum performance standards for heat loss and gain during the winter and summer, which were consequently reflected in the more appropriate orientation of residential buildings, street widths and landscaping. City policies encouraged smaller lot sizes, greater development densities and the protection of agricultural land. A reduction of automobile travel time in favour of bicycles led to reduced energy use.[71]

Davis' plan also recognized the need to knit existing open spaces together with future growth areas, and called for a reconnection of the city with its larger regional landscape. In this regard, the plan created more than 80 kilometres of connected trails and public accessways, and is the first large-scale open space preservation plan in the United States that includes both riparian habitats and agricultural lands that range in scale from the family farm to corporate agribusiness.[72]

In a 1992 document entitled 'Energy Efficient Subdivision Design',[73] planners for the City of Davis identified certain general plan policies as being relevant to the review of development projects: those that encourage energy-efficient subdivision and building design, and those that require site planning to maximize the effects of south-west cooling winds through the design review process.

These policies continue to be used to implement city codes on energy conservation and solar access. Interpretation of basic policies (approved by the City Council in July 1992) show how they have integrated energy-efficient design with a wide range of considerations. Among these are: the preservation of natural features; the siting of streets, lots, buildings and street trees; the provision of mixed use and facilities within walking distance; and the arrangement of higher density and intensified uses near community facilities. In addition, this document includes guidelines on overall neighbourhood design, and design criteria that should be used in the review of subdivisions and planned developments. These have to do with the protection of natural and human-made features, response to climate, drainage systems that minimize impacts on city storm drainage systems and contribute to the underground water regime, pedestrian and bicycle circulation and other related aspects of design.[74] Ordinance No. 1618, for instance, sets out criteria for water conserving and drought tolerant landscapes that require at least 90 per cent of plant materials selected to be well suited to the climate of the region.[75] In addition, Davis' conservation programme recognizes the importance of trees as a natural air-conditioner, since neighbourhoods with shaded narrow streets can be as much as 10°C cooler than those with unshaded streets and use only use half of the amount of electricity for air-conditioning.[76]

Many of these policies, modified and improved over the years, are embodied in 'Village Homes', an innovating 242 home subdivision located on 28 hectares of land. This development addressed issues that many Davis residents were adopting – alternative

Plate 6.9 *Village Homes in Davis, California, on a rainy winter's day*

Backyards and accessways are designed to retain rainwater during and after storms. This project shows great attention to detail. Note change in materials where a walkway crosses a drainage swale modes of transportation, energy efficiency and community interaction.[77] Designed and built by Michael Corbett in the early 1970s, the development includes detention ponds for rainwater, a variety of orchards, community gardens, vineyards and common areas dispersed throughout the neighbourhood, narrow 6 or 7 metre wide cul-de-sac streets, pedestrian and cycle greenways and a south-facing layout for lots and houses. The development also includes an abundant landscape and street trees, many of which are fruit-bearing. A post-occupancy evaluation undertaken in August 1990 compared Village Homes with a standard control subdivision. It concluded, among other factors, that:

- home energy use and energy consumption for transportation purposes are approximately one-third less than in conventional subdivisions, attributable to solar design of homes, less air-conditioning and less use of vehicles;
- residents grow more fruit and vegetables which contribute approximately 25 per cent of the household's annual consumption of these commodities;
- recycling behaviour has been found to be generally higher than in the control subdivision;
- residents appreciate the social attributes of Village Homes, such as semi-public spaces, a community centre and appropriate places for children and social contact.
- residents socialize much more that their counterparts in the control subdivision, and know their neighbours better.[78]

SOME CONCLUDING REFLECTIONS ON URBAN CLIMATE

One may be tempted to comment that the value of plants, landform and water to the creation of beneficial micro-environments has been 'rediscovered' by the contemporary science of climatology. It has begun to measure something that people knew by trial and error and have made use of for generations in pre-industrial built environments. Applying traditional methods of climate control, in effect, now has the blessing of the scientific method.

But there are climatic phenomena that the older cities were rarely, if ever, faced with. Atmospheric pollution, urban heat islands and down draughts from tall buildings, drainage systems and hydrological imbalances are a creation of large industrial cities. Creating favourable habitats by natural means combines traditional wisdom, modern science and intelligent planning. The use of plants and water on the walls, floor and roof surfaces of the city can create natural climatic control and can in large measure restore the energy balance through evaporation of water into the air and the metabolic processes of plants. The arrangement of built and landscape elements can reduce the impact of wind, take advantage of sun and create favourable micro-climatic environments.

Following the principle of economy of means, the natural patterns and materials of the landscape can be made to work for the city environment in new ways and at less cost, compared to the energy costs currently incurred to maintain highly inhospitable conditions. The question 'how can human development *contribute* to the environments it changes?', provides us with a positive and proactive basis for action that can restore healthy climates, biological diversity and productive urban soils. It also provides us with a foundation for internalizing nature in human affairs. And if the natural and human processes that sustain life are integrated and visibly parts of everyday life, we enrich immeasurably the urban environment.

It is evident that climatic forces form a common thread that influences all the other natural and human processes of water, plants, animals, urban farming and city life. Together they are an integration of natural and human systems and interconnected elements that play a vital role in the ecological health and quality of life in cities, and, in the process, provide the multiple opportunities and benefits that we have been examining.

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In this and previous chapters I have tried to show how, by bringing urban and natural processes together at a local level, a new design language emerges that has significance for the evolving form of the city. The forces that have shaped today's urban regions have been governed by unlimited energy resources and by attitudes that have paid little heed to the necessity for a sustainable future, or to the relevance of nature to cities. The urban environment has been managed on a piecemeal basis, treating the economy separately from social issues, or the environment; consequently, solutions to problems have been single-minded, simplistic and fragmented. The pieces of the puzzle have remained separated to the detriment of natural systems and the quality of urban life as an enriching social, environmental and sensory experience.

It has also become evident that the climate of cities must be understood in a wider perspective that crosses regional boundaries, since the influences of solar energy, global wind patterns, the atmosphere, fresh waters, the oceans and continents and human activities on the land, link cities together in a worldwide interconnected whole. Air and water pollution, global warming, depletion of the ozone layer, vanishing forests, poverty and hunger, once thought of as having local consequences, or as being problems that belong somewhere else, now become much debated global issues affecting everyone, and crossing all political boundaries.

Some important and far-reaching shifts in values are beginning to emerge, however, that have to do with notions of renewal, citizen empowerment and action, co-operation as opposed to confrontation between people and governments, and the integration of nature, economy and social agendas in decision-making. Many of the approaches to achieving a sustainable future for cities that may have seemed unworkable or unrealistic in the 1960s are being recognized as achievable and necessary in the last decade of the twentieth century.

Per Stig Moller, the Danish Minister of the Environment wrote in 1991 that

> Economic development must go hand in hand with re-creation of the ecological balance. We must not look on environmental pollution as an isolated problem. This is the vital point that we must always remember when we debate our social and economic problems.[79]

This perspective is increasingly recognized in other political arenas as a central determinant for change. In effect, a long-term investment in things like soil fertility, perpetuation of forests and environmental stability may be seen as a better bargain than quick profits gained at the expense of the future. The practical application of the principles outlined in this book depends less on altruistic motives, and more on what makes practical sense. Alternative ways of doing things are eventually done for pragmatic reasons, because the alternatives provide tangible benefits, in ecological, economic or social terms. Many of the examples I have illustrated are occurring fortuitously under our noses, but are now being recognized for what they are, and for the lessons they can teach. Where necessity prevails, such as in times of war, or the perennial problems of poverty, the need to grow food, recycle materials or engender a sense of community purpose will continue to be a matter of survival. In the 1990s, society has begun to recognize that global or local environmental sustainability will be determined largely by our cities. Such a goal will be dependent on finding ways to protect natural wealth, regenerate the processes of urban nature and adopt more environmentally conscious lifestyles.

The idea of interdependence between human communities and nature, enshrined in Barry Commoner's well known principle that 'everything is connected to everything else', illustrates that the more one learns about one's home place, the more relevant this becomes to the larger global community, and the greater the need to protect biological diversity beyond local boundaries. Global thinking must become a framework for local action, since the two are inextricably linked. The key to environmental sanity and civilized urban life in the twenty-first century may well lie in how we deal with these interrelated realities.