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Climate and site development

Part 2: Influence of microclimate

This Digest describes how microclimate is affected by the geography and topography of a site and its surroundings, and how it can be further influenced by the arrangement of buildings and landscape features. It reviews techniques for planning a climatically sensitive site layout, giving maximum benefit from fine weather and some protection from adverse weather. This can benefit building performance by reducing energy consumption and improving durability, and can make the spaces around buildings more attractive and useful by providing better conditions for outdoor activities.

This Digest is published in three parts. The other two parts are:
Part 1: General climate of the UK
Part 2: Influence of microclimate
Part 3: Improving microclimate through design.

The numbering of references, tables and illustrations continues through the three parts: references and further reading are listed in Part 3.

Fig 8 Tree shape revealing wind exposure

Site layout, built form, external materials and landscape design are all elements that can help to create a sheltered environment, exploiting favourable climatic influences and protecting against unfavourable ones. For maximum effect the various elements need to be well integrated into the overall design. The primary concern in the UK is to mitigate the cold, wind and wet of the relatively long cool season. The intention will be to enhance, as far as practicable, the 'heat island' effect noticeable in large conurbations, but present to some degree in all built-up areas. Several processes are involved:

- Solar heat absorbed and re-emitted by external surfaces exerts a warming effect on the external spaces around buildings: average air temperatures will tend to be higher, the daily range of air temperature reduced and more re-emitted radiant heat available. Any such warming will reduce space heating energy demands of the buildings, which depends largely on inside/outside temperature differences and radiant exchanges. Maximising the benefits of solar heat requires good solar access to external spaces and surfaces, and attention to the thermal properties of external building and landscape materials.
- Reduction of wind speed by wind control should improve the microclimate around the buildings. This can be direct, in terms of reduced mechanical and thermal effects on buildings and on people, and indirect, by avoiding the dissipation of external heat gains by mixing with colder air. Wind control implies the choice of built forms least likely to disturb wind flow patterns near the ground, and the use of wind sheltering design elements such as courtyard forms, windbreak walls and fences and shelterbelts.
- If external surfaces are wet for less of the time, the amount of heat consumed by evaporation will be reduced. Wind shelter may help to reduce the impact of driving rain; this can have significant effects on the thermal performance of external walls. Hard surfaces that drain and dry more quickly will tend to retain more heat and thus have a greater influence on air temperature and radiant exchanges.

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Good solar access is also an aim in passive solar design, so as to maximise useful solar gains within buildings. Combining passive with microclimate design allows useful energy benefits from each, together with the non-energy advantages of microclimatic design — in many cases a more agreeable external environment over a longer period.

Ideally, microclimate should be a factor in selecting sites for many types of building. However, with the restricted availability of land for development in many parts of the UK, it will rarely be possible to select a site on the basis of suitable microclimate. This Digest therefore concentrates on making the best of an already-chosen site. This reflects the fact that some building is certain to take place on unfavourable sites, such as north-facing slopes, windy ridges and frost hollows. In such cases integration of built form and the landscape to improve the microclimate is particularly desirable.

The approach is relevant to the design both of individual buildings and of building complexs, eg housing estates and industrial parks: in general the larger the site the greater the potential for improving its microclimate. Beyond this, there may be scope for continuity of a microclimate design approach between adjoining sites, or for the complementary use of publicly owned, non-developable land, eg for planted wind shelter. The impact of microclimate improvement on building energy use will tend to be greatest for small, low-rise buildings, having a large surface-to-volume ratio and occupying the most easily sheltered, lowest layers of the atmospheric boundary layer.

There could be opportunities to reflect climatic factors in the exercise of planning control, although building energy efficiency does not yet feature in development plans. Allied to other factors, such as protection from noise or industrial pollution, zones with good microclimatic potential might be preferred for housing, shopping, or open-air leisure activities. Less favoured zones could be allocated to other uses (noting that the siting of highways itself needs to take account of microclimate as it effects fog, ice and wind). Other trends in development, such as leisure facilities in the contryside, could also benefit from the principle of a 'managed microclimate'.

High buildings pose special problems. Although fewer have been built in recent years, the presence of one or more high buildings can degrade the local climate on adjoining sites. Wind speeds at and near ground level can be significantly increased for extended periods, and tall buildings cast extensive shadows which partly block solar access to adjacent land over a wide area. In addition to their well-documented detrimental effects on external comfort, high buildings may also significantly increase the costs of space heating in surrounding low-rise buildings[10].

Guidance on wind environment around high buildings is given in Digest 141.

ASSESSING A SITE BEFORE DEVELOPMENT

The climate of a particular site will often differ from the 'area average' indicated by maps or tables in several respects. Table 1, relating geographic and topographic features to the climatic variables they affect, can be used as a check list. Even if these effects can be assessed only qualitatively, this should allow the microclimatic character of the undeveloped site to be better understood, as the context in which a climatically site design can be developed. Additional guidance can be found in Reference 9.

The movement of air up or down a slope, even a modest one, can be important, especially for sites at or near the bottom. This effect is due to buoyancy: air warmed by the ground on a calm, sunny day will rise up a slope (anabatic flow), while air cooled by the ground on a calm, clear night will drift down it (katabatic flow). Typical speeds for such flows in the UK are from 1 to 2 m/s, depending on the extent and steepness of the slope. Katabatic flows are more important for site development: they render hollows and valley floors colder than locations part way up the sides and, especially, increase the severity and persistence of frosts where cold air is trapped. It is important to recognise where such flows are likely, to avoid creating cold air traps at unsuitable points in the layout of buildings or landscape features.

The most favourable location in a valley is often referred to as the 'thermal belt', lying just above the level to which pools of cold air build up, but below the point at which the chilling effects of the wind become dominant. The wind exposure of upland sites, eg hill-tops and moorland, is usually evident on all but the calmest days. Even if the altitude is insufficient to result in markedly reduced air temperatures, the greater frequency of days when windiness is noticeable affects both external comfort and energy use in buildings. Severe wind exposure will often be revealed in the form of trees and hedges (Figure 8).

The crests of hills and ridges can present particular problems due to the way wind flows over them. The velocity:height profile is compressed, compared with that above level ground, and strong winds can occur very near ground level. For example, around the crest of a 1 in 3 hill, gust speeds only a few metres above the ground will be about one-third greater than those at a height of 10 m above a level situation upwind of the hill (Figure 9). Because of this, attempts to establish natural shelter such as trees may have limited success. The exposure of an upland site will depend on the adjoining terrain in different directions. For example, sites with a westerly aspect will generally be more exposed than those with an easterly aspect; a site on an isolated hill will tend to be more exposed than on a hill within a group.

Table 1 includes the effects on climate of urban and suburban development. Towns and cities can show marked increases in temperature (the 'heat island' effect) both in winter and, especially, in summer; ideally, climatically sensitive site design needs to exploit the former but counter the latter. The effect of large conurbations on space heating degree-day total in Central London is estimated to be some 10% lower than in its suburbs (Reference 4). Effects such as reduced wetting and long-wave radiation losses and, conversely, reduced solar gains, also influence the fabric heat balance of buildings in towns.

All scales of built development, from outer suburbs to city centres, tend to reduce average wind speeds in the immediate boundary layer. In general the denser the development the greater the reduction, but this is accompanied by a proportionate increase in turbulence. Whether this turbulence produces an uncomfortable wind climate at ground level in outdoor spaces depends on the local arrangement and form of buildings: Tables 7 and 8 in Part 3 suggest ways in which wind sensitivity can be reduced. Existing buildings in the vicinity of a site may produce wind funnelling or downdraughts that influence needs for wind control and protection.

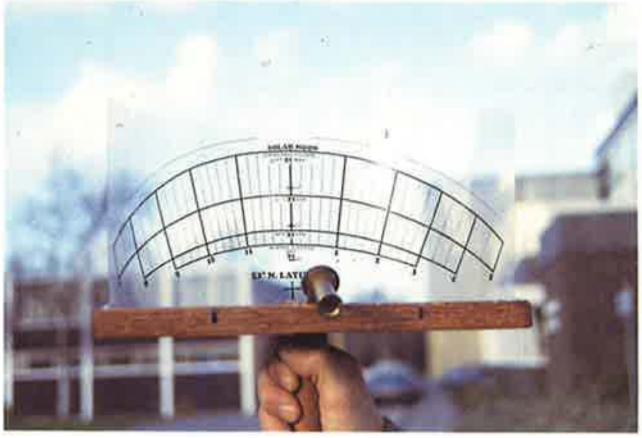

Fig 10 Instrument for measuring horizon profile ('solar site selector')

The edges of built-up areas may present particular needs for wind protection. Influences include the directions of cold wind and driving rain and the effects of altitude, topography and any shelter offered by the town itself. Within built-up areas, large open spaces may increase the wind exposure of adjoining buildings. The way in which ground roughness changes from countryside to suburb is important in determining local wind exposure; this may call for specialised meteorological advice.

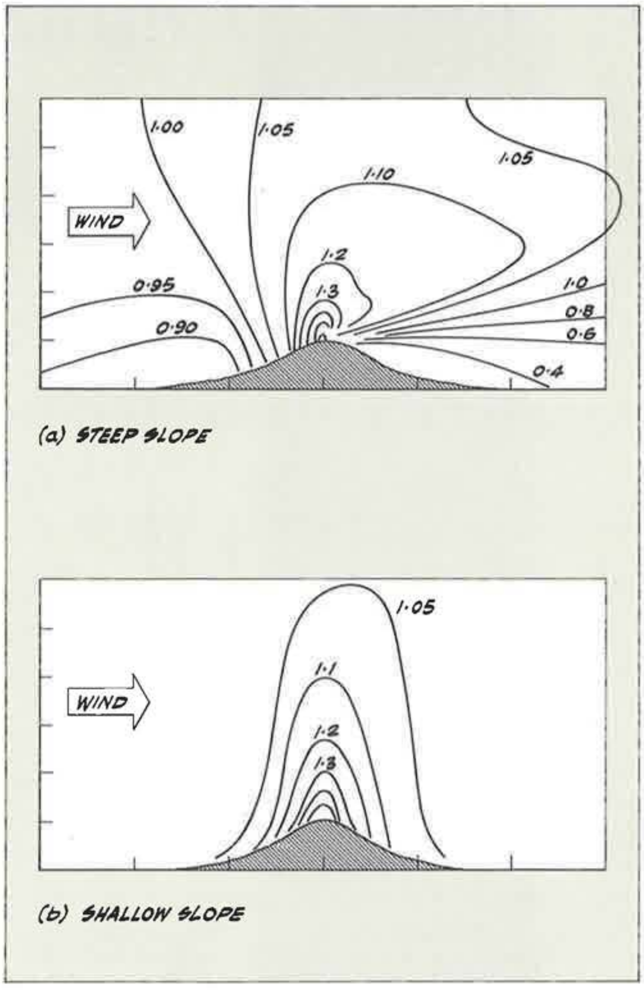

Fig 9 Typical velocity profiles at crest of steep hill

The effects of local factors, both natural and artificial, can be quantified approximately for wind speeds, driving rain amounts, solar irradiation and daylight. The effects of topography and ground roughness on the one hand, and of atmospheric clarity, obstructions and reflections on the other, have been codified (see References 5, 6 and 8). Approximate methods of estimating certain climatic variables at any site in the UK have been developed for natural environments[11], and these may be useful for areas of the country remote from meteorological stations.

More precise information on the likely microclimate of a site can often be obtained from meteorologists, especially if they are familiar with the locality. Site survey techniques may also be useful. Direct measurement of the weather over a period may be possible using an automatic weather station, but the data need to be related to a reference point (eg a meteorological station) in order to make inferences about long-term microclimate. It may also be difficult to assess wind directions accurately from measurements taken at only one, low-level point. For overshadowed sites, solar access can be assessed using simple instruments to measure the horizon profile, as shown in Figure 10: such measurements can be used directly in some of the design aids described in Part 3 of this Digest.

In appraising a site, account should also be taken of the permancence of existing vegetation, buildings or landscape features outside the site boundary, and of the likely consequences of new developments on adjacent sites. Further considerations include the type and wetness of the soil, as this may affect the potential for planted wind shelter. The water table will also be relevant if underground, or partly underground, buildings are contemplated.

Table 1 Topographic influences on climatic variables

	Minimum air temperature	Maximum air temperature	Accumulated temperature difference (heating degree-day) Total	Relative humidity	Wind speed and direction	Cloud cover	Radiation: incoming (solar) and outgoing (long-wave)	Rainfall	Snowfall and snow cover
Altitude	Lower at higher altitudes	Lower at higher altitudes	Higher at higher altitudes	Higher at higher altitudes	Higher speeds at higher altitudes	Increases with altitude; frequency of hill fog also increases with altitude	Radiation gains and losses decrease with altitude due to increased cloud and hill fog	Rainfall increases with altitude; proportion of rainfall to total precipitation decreases	Snowfall increases with altitude; its wetness decreases with altitude
Slope	Determines speed of cold air drainage (katabatic flow); this may be directed by surface features	*Summer:* highest temperature at bottom of slope; *Winter:* variable	Can be higher on valley floor than in 'thermal belt' higher up its slopes	No direct influence	Air may continue to move even in otherwise calm conditions, due to anabatic and katabatic flows	May increase with angle of slope, particularly in mountainous areas	According to aspect — see below	Depends on angle of slope and overall change in altitude: significant increase in rainfall on windward slopes when altitude change exceeds 100 m	Depends on angle of slope and overall change in altitude: significant increase in snowfall on windward slopes when altitude change exceeds 100 m
Aspect	Aspect fairly unimportant (see *Slope* for cold air drainage)	Higher on south slopes than north, and on west slopes than east; highest in north/south valleys and on south-facing slopes	Higher on north-facing slopes, lower on south-facing slopes	Absolute humidity unaffected, but relative humidity affected due to air temperature differences	Will depend on aspect of slope and on wind direction direction, eg windward or leeward slopes	Extremely variable, depending on time of year, type of air mass, etc	Radiation gains highest on south-facing slopes, lowest on north-facing slopes	Increases on windward slopes, decreases on leeward slopes, for rain-bearing winds	Increases on windward slopes, decreases on leeward slopes for snow-bearing wind; snow cover greatest on north-facing slopes
Albedo (Ground reflectance)	No direct influence, but likely to be lower for higher albedos, higher for lower albedos	Likely to be lower for higher albedos, higher for lower albedos	Higher albedos likely to increase night-time degree-hours and decrease day-time degree-hours, and vice-versa	Can increase or decrease rate of evaporation and hence humidity	Can increase or decrease anabatic or katabatic flows; local differences in albedo can create pockets of ascending or decending air	Low albedos can induce convective cloud formation, especially in the afternoon	Lower albedos absorb more short-wave radiation but emit more long-wave radiation, and vice-versa	No direct influence	By influencing ground and air temperatures albedo can encourage newly fallen snow either to settle or melt

Nature of Surface	Higher with grass than with bare soil; lowest with bare rock	Lower with grass than with bare soil; highest with bare rock	Compaction of soil or surface can influence HDD	For short grass, evaporation is greatest after rain; water surface evaporation greatest on clear, windy days	Roughness determines turbulence and local currents	Depends on albedo	Depends on albedo	No direct influence, but affects subsequent percolation, runoff or evaporation of rainfall	Snow cover affected by both albedo and ground roughness
Vegetation	Higher when there is more vegetation	Lower when there is more vegetation	Lower when there is more vegetation; the taller the vegetation the greater the influence	Higher when there is more vegetation; depends on density of growth	Lower when speed within the vegetation canopy	No influence	Depends on albedo and nature of surface; penetration variable, according to character of vegetation	No direct influence, but affects percolation runoff and evaporation	Snow cover and snow melt rate affected by character of vegetation
Hills and valleys	Lower in frost hollows; can be higher in 'thermal band' on slopes above valley, or wherever inversion occurs; higher up, lapse rate of temperature with altitude means lower minima	Higher on valley slopes than on valley floor in winter, vice-versa in other seasons, due to anabatic and katabatic flows; higher up, lapse rate of temperature with altitude means lower maxima	Generally higher on valley floor than on slopes except at great altitudes	Valleys can trap moist air, inhibiting mixing	In general, wind speed is higher at or near hill tops and is lower in valleys, except where valley funnels the wind; important if a dominant wind direction is funnelled	Higher long wave radiation losses from 'corrugated' surface can lower temperatures and cause increased cloudiness	Shaded areas will be denied some radiation gain, typically at low solar altitudes (early morning and late afternoon or evening)	Windward slopes wetter, leeward slopes drier, for rain-bearing winds	Snowfall increases with altitude, but locally snow cover may be deeper due to drifting or shallower due to scouring by wind
Coasts	Generally higher than inland, especially with relatively warm sea	Generally lower than inland, except in winter with relatively warm sea	Generally lower than inland, especially with relatively warm sea	Higher than at low altitudes inland (rh affected by air temperature differences at higher altitudes)	Speeds of onshore winds higher than inland; sea breezes develop on warm summer days	Little effect; more than inland in winter, less in summer, for onshore winds	Higher with clear marine atmosphere, except during sea fog	Little effect; higher than at low altitudes inland in winter with onshore winds but lower in summer	Lower than inland
Urban Areas	Higher with higher densities and larger urban areas, due to 'heat island' effect	Higher with higher densities and larger urban areas, due to 'heat island' effect	Lower with higher densities and larger urban areas	Lower with higher densities and larger urban areas	Generally lower than in open country, but may be higher locally, especially near high buildings	Little effect, although may be more convective cloud	Lower with polluted urban atmospheres	Little effect, although may be more convective showers in summer	Little effect on snowfall (except in very large cities) but snow cover less persistent

ENHANCING THE MICROCLIMATE OF A SITE

The setting of a site will usually have revealed some microclimatic advantages and disadvantages, deriving from its general location and immediate surroundings. Developing a climatically sensitive site plan involves a repertoire of techniques to exploit the advantages and counter the disadvantages. Since the design of the site layout and buildings has to be considered as a whole, this is a matter for the initial stages of design: the potential for later intervention or adaptation is limited. The aim is to optimise the overall microclimatic performance of the buildings and site.

Enhancing the microclimate of a site can achieve a range of aims, both economic and environmental (Table 2). Reducing the costs of space heating or cooling, together with improved durability, has an obvious, quantifiable attraction. Environmental benefits are not insignificant; they could allow a useful increase in the number of days each year when outdoor conditions are comfortable. This is valuable in an age of increasing leisure. A favourable external environment will generally improve user satisfaction, and may increase the value of a property or make it easier to sell or let.

Table 3 lists the principal means by which the microclimate of a site can be improved. It will rarely be possible to achieve a high level of enhancement over the entire area of a site, so there will usually be further choices to be made on its subdivision. For example recreational areas can be located in the most favoured spots, garaging or refuse storage in the least favoured. Some measures involve little or no additional costs; others, eg earthworks, walls, planting and the extra land they occupy, involve both capital and maintenance costs. Also, building managers need to be made aware of the significance of such features in the site's design, if the benefits are to be fully realised.

An improved site microclimate can reduce energy costs for space heating in a number of ways (Table 4). It is difficult to quantify these reliably at present but, even if some of the gains are small, their combined effect should be significant. For residential developments, average savings in heating costs of at least 5% could be expected (compared to typical site layouts), even in the more sheltered or favourable parts of the British Isles[12]. On exposed sites where wind-induced heat losses are greater, substantially greater savings should be realised. Combination of microclimatic enhancement with passive solar design can make a major impact on space heating costs, especially during the longer heating season in the North.

Detailed guidance on these techniques is given in Part 3 of this Digest.

Table 2 Aims of enhancing microclimate in the spaces around buildings

Main aims

- To reduce the cost of winter heating
- To reduce the incidence of summertime overheating (or the cost of summer cooling, where applicable)
- To maximise outdoor comfort, in summer and winter conditions

Subsidiary aims

- To improve the durability of building materials
- To facilitate open-air drying of clothes and furnishings
- To provide a better visual environment in the spaces around buildings
- To encourage the growth of plants
- To discourage the growth of mosses and algae (for both aesthetic and safety reasons)

Table 3 Means of enhancing microclimate in the spaces around buildings

Solar access

1 Allow maximum daylight into space and buildings

2 Allow maximum solar radiation into space and buildings (winter: low angle sun)

3 Shade space and windows from prolonged exposure to strong solar radiation (summer: high angle sun)

4 Protect space and windows from glare

Wind Protection

5 Protect space and buildings from important wind directions (eg dominant winds, cold winds)

6 Prevent buildings and landscape features from generating unacceptable wind turbulence

7 Protect space and buildings from driving rain and driving snow

8 Protect space and buildings from cold air 'drainage' (katabatic flows) at night

BUT retain enough air movement to disperse pollutants

Features

9 Provide external thermal mass to moderate temperature extremes

10 Where possible, use vegetation for sun shading and wind protection; transpiration helps moderate high temperatures (summer)

11 Provide surfaces that drain and dry readily

12 Provide water for cooling by evaporation, eg pools, fountains, cascades (summer)

Table 4 Ways in which enhancing microclimate can save energy for space heating

Ways	**Means** *(from Table 3)*
• *Increased air temperature:* if the external air surrounding buildings remains warmer the internal/external temperature difference will be smaller, reducing the amount of heat lost by both conduction and ventilation/infiltration. Some influence on air temperature may be possible by deliberately 'storing' solar heat in external thermal mass, and by wind control to limit the mixing of cold and warm air	2, 5, 6, 9, 11
• *Increased surface temperatures:* if the external surfaces of buildings are warmed by direct or reflected solar radiation, or by long-wave radiation emitted by other warmed external surfaces, the internal/external surface temperature difference will be smaller, reducing the amount of heat lost by conduction	2
• *Reduced air change rate:* wind control can reduce high rates of pressure-difference-driven infiltration of external air into the building (most significant for older buildings, less so for modern buildings with good draughtproofing)	5, 6
• *Reduced air movement within envelope:* wind control can reduce high rates of pressure-difference-driven movement of external air into the building envelope (which would otherwise increase its thermal transmittance)	5, 6
• *Increased surface resistance:* wind control can increase surface resistance through reduced air movement and mixing (important for poorly insulated areas such as glazing)	5, 6
• *Reduced moisture effects on thermal performance of envelope:* wind control can reduce the wetting of the building fabric (which would otherwise increase its thermal transmittance) by wind-driven rain. Reduced air movement will also reduce the rate of evaporative heat loss from damp materials, so these two factors interact	7, 11

Notes

For any particular microclimate, the significance of each factor will vary between buildings of different form, construction, insulation, fenestration, etc.

This table does not include the effects of designing site layouts to maximise passive solar gains or daylighting within buildings.

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