2 Atmosphere and weather

2.1 Diurnal energy budgets

An energy budget refers to the amount of energy entering a system, the amount leaving the system and the transfer of energy within the system. Energy budgets are commonly considered at a global scale (macro-scale) and at a local scale (micro-scale). However, the term microclimate is sometimes used to describe regional climates, such as those associated with large urban areas, coastal areas and mountainous regions.

Figure 2.1 shows a classification of climate and weather phenomena at a variety of spatial and temporal scales. Phenomena vary from small-scale turbulence and eddying (such as dust devils) that cover a small area and last for a very short time, to large-scale anticyclones (high-pressure zones) and jet streams that affect a large area and may last for weeks. The jet stream that carried volcanic dust from underneath the Eyjafjallajökull glacier in Iceland to northern Europe in 2010 is a good example of jet-stream activity (Figure 2.2).

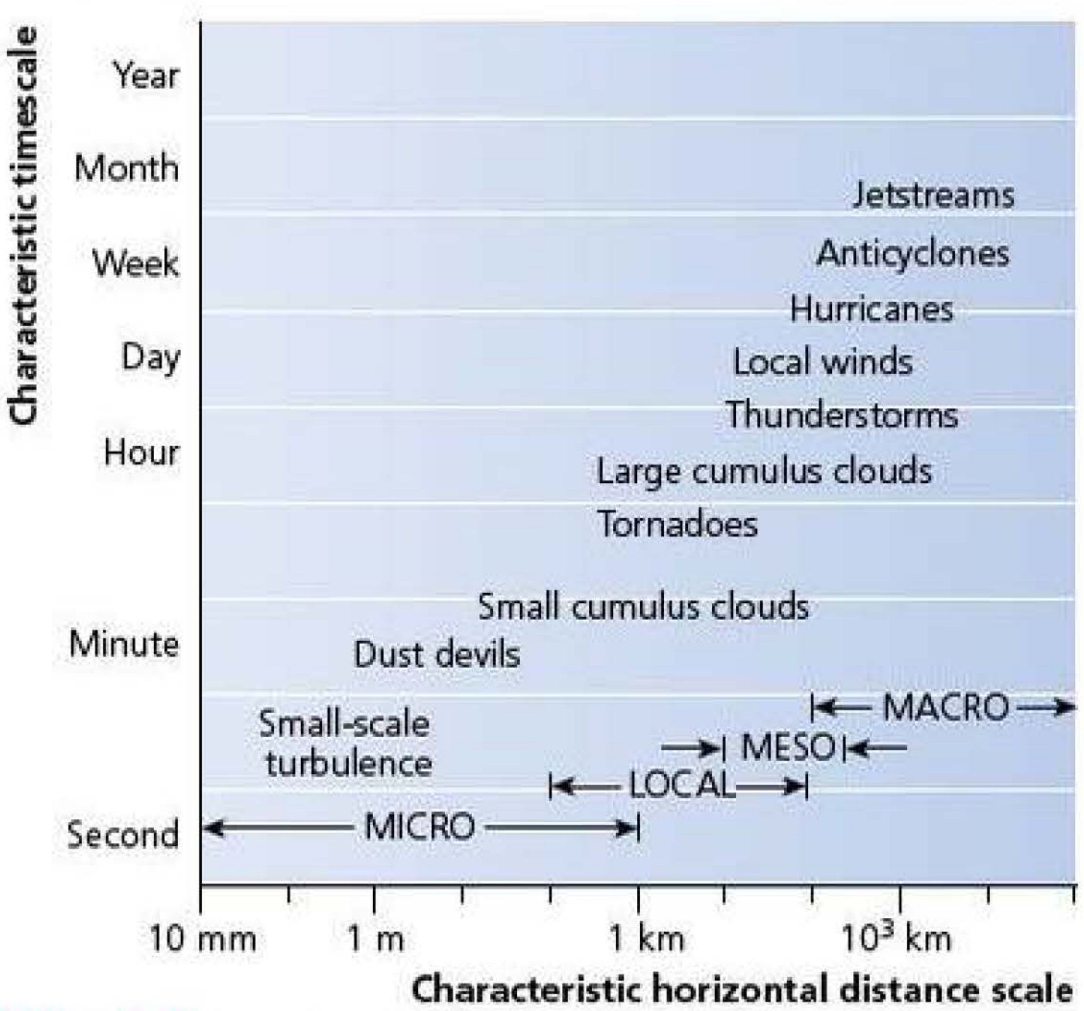


Figure 2.1 Classification of climate and weather phenomena at a variety of spatial and temporal scales

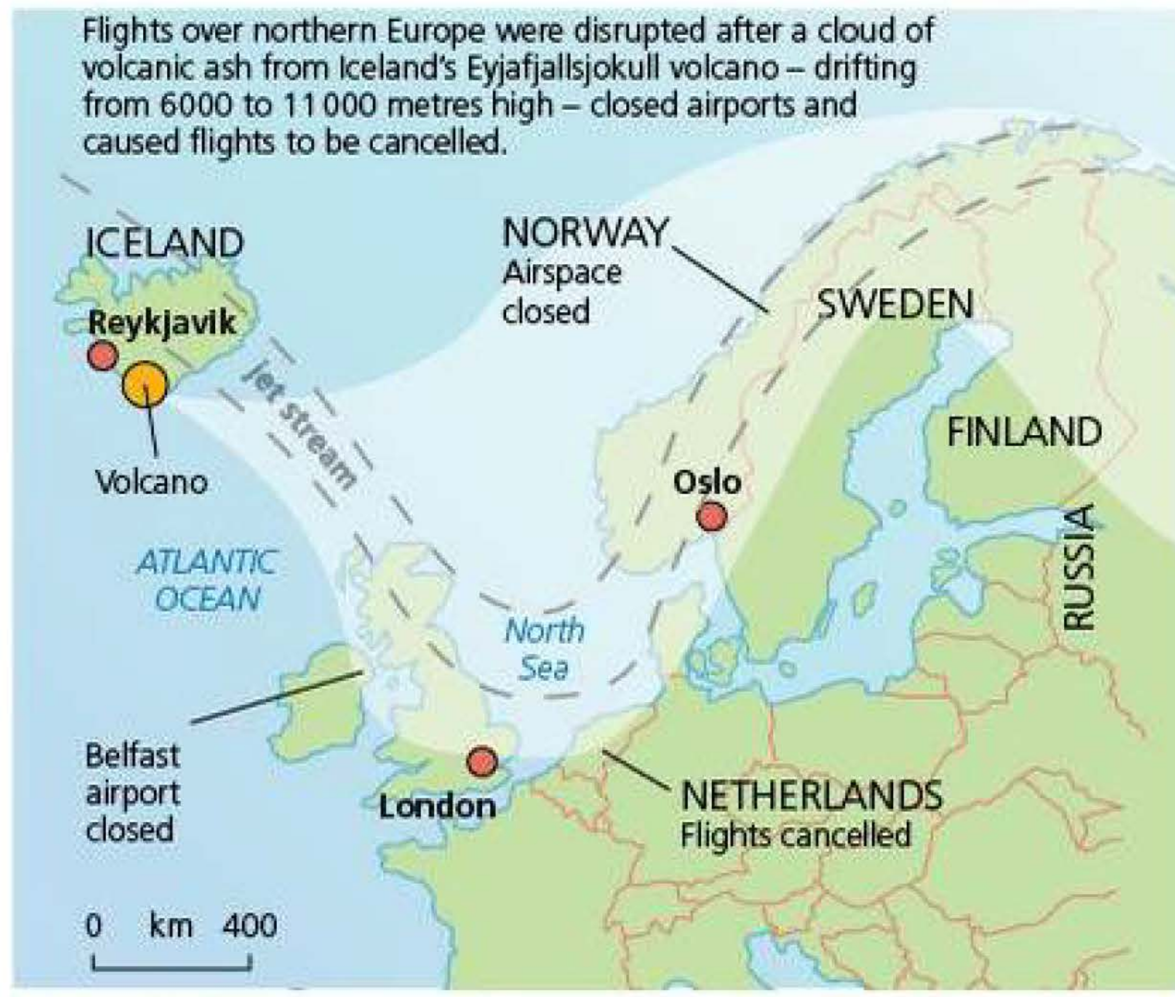


Figure 2.2 Jet-stream activity and the transfer of dust from Eyjafjallajökull, Iceland

These different scales should not be considered as separate scales but as a hierarchy of scales in which smaller phenomena may exist within larger ones. For example, the temperature surrounding a building will be affected by the nature of the building and processes that are taking place within the building. However, it will also be affected by the wider synoptic (weather) conditions, which are affected by latitude, altitude, cloud cover and season, for example.

Daytime and night-time energy budgets

There are six components to the daytime energy budget:

- incoming (shortwave) solar radiation (insolation)
- reflected solar radiation
- surface absorption
- sensible heat transfer
- long-wave radiation (Figure 2.3)
- latent heat (evaporation and condensation).

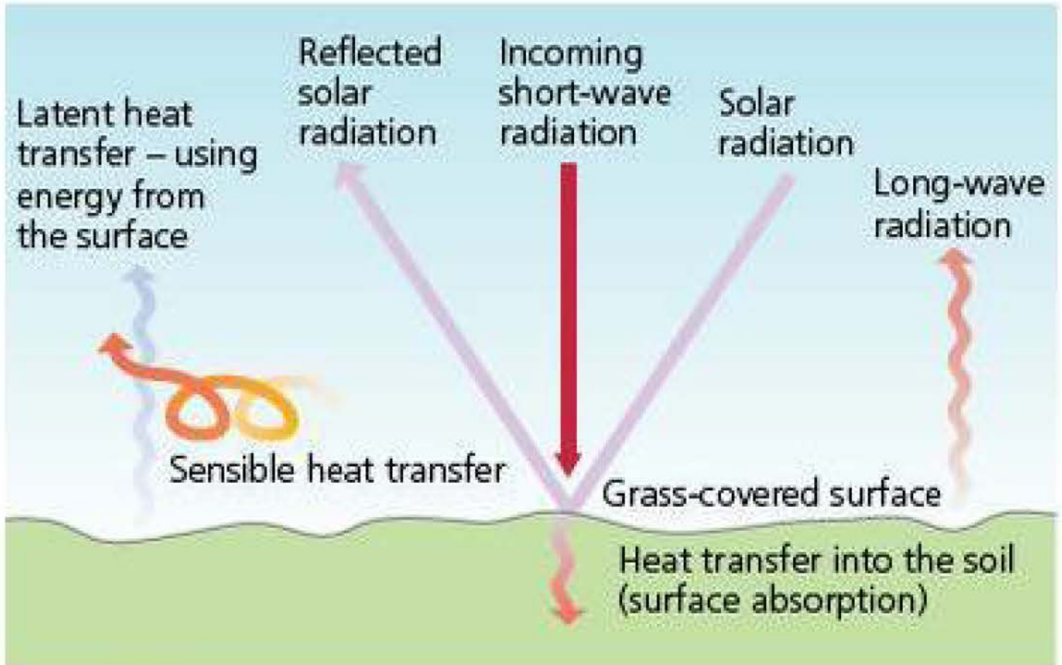


Figure 2.3 Local energy budget – daytime

These influence the gain or loss of energy for a point at the Earth's surface. The daytime energy budget assumes a horizontal surface with grass-covered soil and can be expressed by the formula:

energy available at the surface = incoming solar radiation – (reflected solar radiation + surface absorption + sensible heat transfer + long-wave radiation + latent heat transfers)

In contrast, the night-time energy budget consists of four components:

- long-wave Earth radiation
- latent heat transfer (condensation)
- absorbed energy returned to Earth (sub-surface supply)
- sensible heat transfer (Figure 2.4).

Incoming (shortwave) solar radiation

Incoming solar radiation (insolation) is the main energy input and is affected by latitude, season and cloud cover (Section 2.2). Figure 2.5 shows how the amount of insolation received varies with the angle of the Sun and with cloud type. For example, with strato-cumulus clouds (like those in Figure 2.6) when the Sun is low in the sky, about 23 per cent of the total radiation transmitted is received at the Earth's surface – about 250 watts per m^2. When the Sun is high in the sky, about 40 per cent is received – just over 450 watts per m^2. The less cloud cover there is, and/or the higher the cloud, the more radiation reaches the Earth's surface.

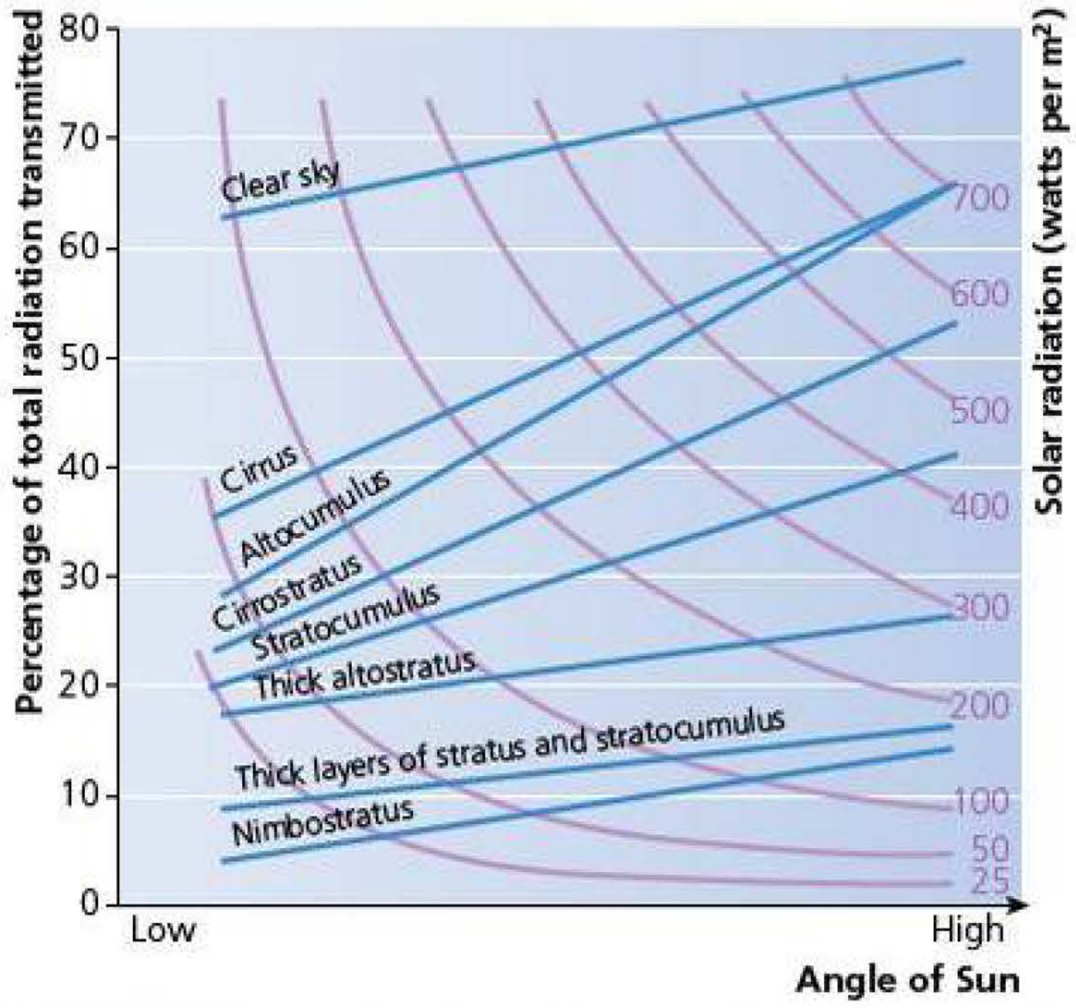


Figure 2.5 Energy, cloud cover/type and the angle of the Sun

Figure 2.6 Stratocumulus clouds

Reflected solar radiation

The proportion of energy that is reflected back to the atmosphere is known as the albedo. The albedo varies with colour – light materials are more reflective than dark materials (Table 2.1). Grass has an average albedo of 20–30 per cent, meaning that it reflects back about 20–30 per cent of the radiation it receives.

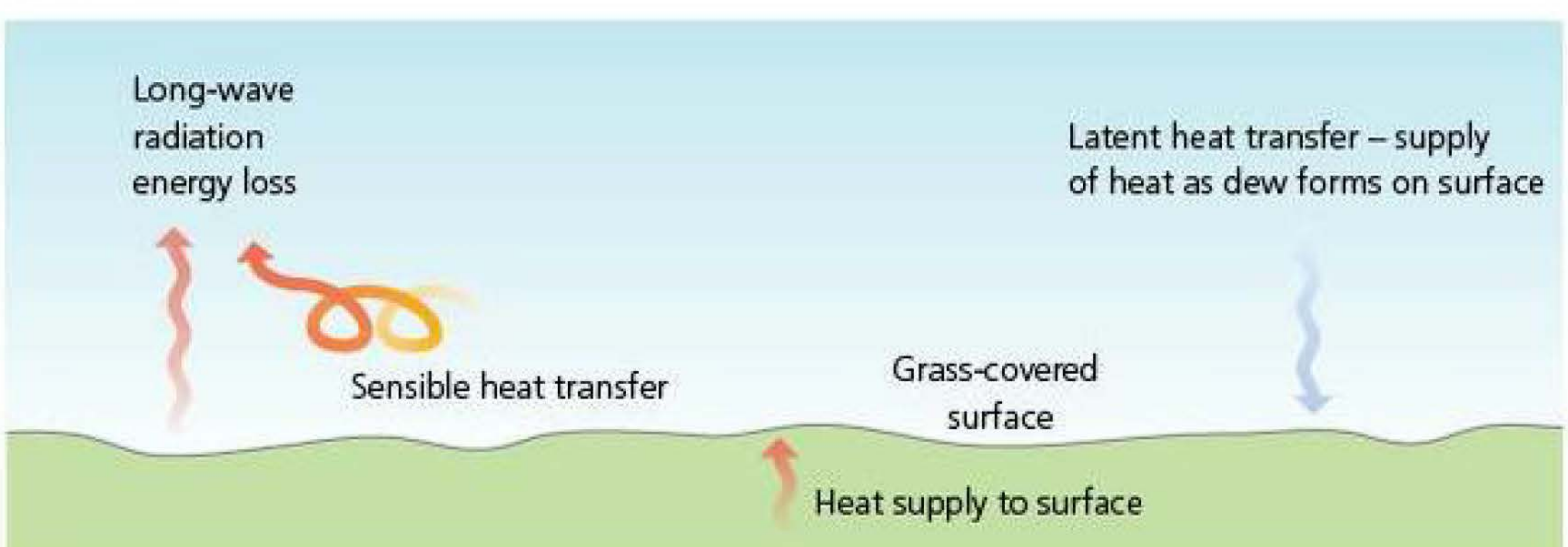


Figure 2.4 Night-time energy budget

Table 2.1 Selected albedo values

Surface	Albedo (%)
Water (Sun's angle over 40°)	2–4
Water (Sun's angle less than 40°)	6–80
Fresh snow	75–90
Old snow	40–70
Dry sand	35–45
Dark, wet soil	5–15
Dry concrete	17–27
Black road surface	5–10
Grass	20–30
Deciduous forest	10–20
Coniferous forest	5–15
Crops	15–25
Tundra	15–20

Section 2.1 Activities

1 The model for the daytime energy budget assumes a flat surface with grass-covered soil. Suggest reasons for this assumption.
2 Study Table 2.1.
   a What is meant by the term *albedo*?
   b Why is albedo important?

Surface and sub-surface absorption

Energy that reaches the Earth's surface has the potential to heat it. Much depends on the nature of the surface. For example, if the surface can conduct heat to lower layers, the surface will remain cool. If the energy is concentrated at the surface, the surface warms up.

The heat transferred to the soil and bedrock during the day may be released back to the surface at night. This can partly offset the night-time cooling at the surface.

Sensible heat transfer

Sensible heat transfer refers to the movement of parcels of air into and out of the area being studied. For example, air that is warmed by the surface may begin to rise (convection) and be replaced by cooler air. This is known as a convective transfer. It is very common in warm areas in the early afternoon. Sensible heat transfer is also part of the night-time energy budget: cold air moving into an area may reduce temperatures, whereas warm air may supply energy and raise temperatures.

Long-wave radiation

Long-wave radiation refers to the radiation of energy from the Earth (a cold body) into the atmosphere and, for some of it, eventually into space. There is, however, a downward movement of long-wave radiation from particles in the atmosphere. The difference between the two flows is known as the net long-wave radiation balance. During the day, the outgoing long-wave radiation transfer is greater than the incoming long-wave radiation transfer, so there is a net loss of energy from the surface.

During a cloudless night, there is a large loss of long-wave radiation from the Earth. There is very little return of long-wave radiation from the atmosphere, due to the lack of clouds. Hence there is a net loss of energy from the surface. In contrast, on a cloudy night the clouds return some long-wave radiation to the surface, hence the overall loss of energy is reduced. Thus in hot desert areas, where there is a lack of cloud cover, the loss of energy at night is maximised. In contrast, in cloudy areas the loss of energy (and change in daytime and night-time temperatures) is less noticeable.

Latent heat transfer (evaporation and condensation)

When liquid water is turned into water vapour, heat energy is used up. In contrast, when water vapour becomes a liquid, heat is released. Thus when water is present at a surface, a proportion of the energy available will be used to evaporate it, and less energy will be available to raise local energy levels and temperature.

During the night, water vapour in the air close to the surface can condense to form water, since the air has been cooled by the cold surface. When water condenses, latent heat is released. This affects the cooling process at the surface. In some cases, evaporation may occur at night, especially in areas where there are local sources of heat.

Dew

Dew refers to condensation on a surface. The air is saturated, generally because the temperature of the surface has dropped enough to cause condensation. Occasionally, condensation occurs because more moisture is introduced, for example by a sea breeze, while the temperature remains constant.

Absorbed energy returned to Earth

The insolation received by the Earth will be reradiated as long-wave radiation. Some of this will be absorbed by water vapour and other greenhouse gases, thereby raising the temperature.

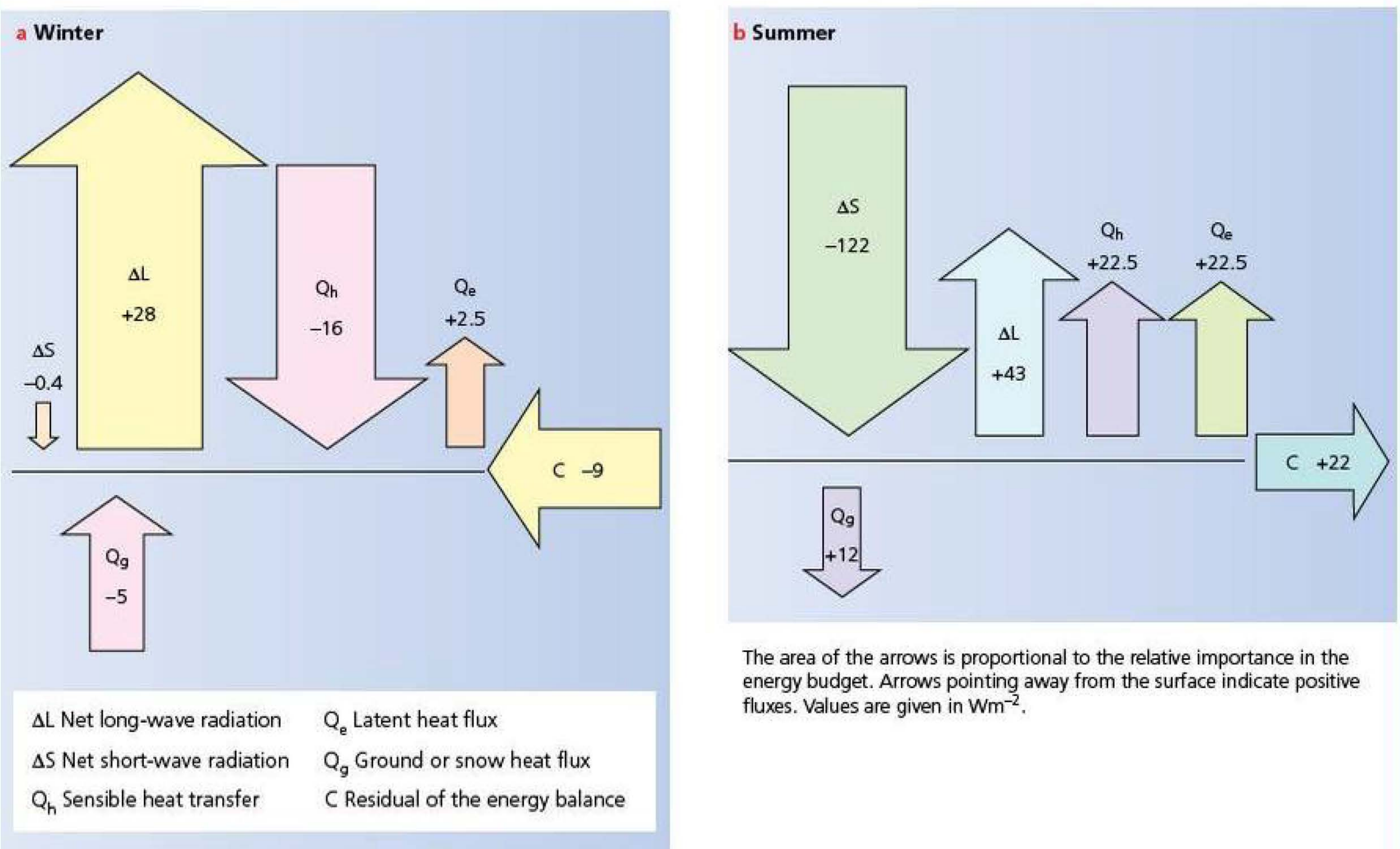
Temperature changes close to the surface

Ground-surface temperatures can vary considerably between day and night. During the day, the ground heats the air by radiation, conduction (contact) and convection. The ground radiates energy and as the air receives more radiation than it emits, the air is warmed. Air close to the ground is also warmed through conduction. Air movement at the surface is slower due to friction with the surface, so there is more time for it to be heated. The combined effect of radiation and conduction is that the air becomes warmer, and rises as a result of convection.

At night, the ground is cooled as a result of radiation. Heat is transferred from the air to the ground.

Case Study: Annual surface energy budget of an Arctic site – Svalbard, Norway

The annual cycle of the surface energy budget at a high-arctic permafrost site on Svalbard shows that during summer, the net short-wave radiation is the dominant energy source (Figure 2.7). In addition, sensible heat transfers and surface absorption in the ground lead to a cooling of the surface. About 15 per cent of the net radiation is used up by the seasonal thawing of the active layer in July and August (the active layer is the layer at the top of the soil that freezes in winter and thaws in summer). During the polar night in winter, the net long-wave radiation is the dominant energy loss channel for the surface, which is mainly compensated by the sensible heat transfer and, to a lesser extent, by the ground heat transfer, which originates from the refreezing of the active layer. The average annual sensible heat transfer of $-6.9\,Wm^{-2}$ is composed of strong positive transfers in July and August, while negative transfers dominate during the rest of the year. With $6.8\,Wm^{-2}$, the latent heat transfer more or less compensates the sensible heat transfer in the annual average. Strong evaporation occurs during the snowmelt period and particularly during the snow-free period in summer and autumn. When the ground is covered by snow, latent heat fluxes through sublimation of snow are recorded, but are insignificant for the average surface energy budget.



The area of the arrows is proportional to the relative importance in the energy budget. Arrows pointing away from the surface indicate positive fluxes. Values are given in Wm^{-2}.

Figure 2.7 Energy budgets for Svalbard

Section 2.1 Activities

1 With reference to Figure 2.7, draw the likely *night-time* energy budgets for Svalbard in summer and in winter.

2 Figure 2.8 shows rural and urban energy budgets for Washington DC (USA) during daytime and night-time. The figures represent the proportions of the original 100 units of incoming solar radiation dispersed in different directions.

a How does the amount of insolation received vary between the rural area and the urban area?

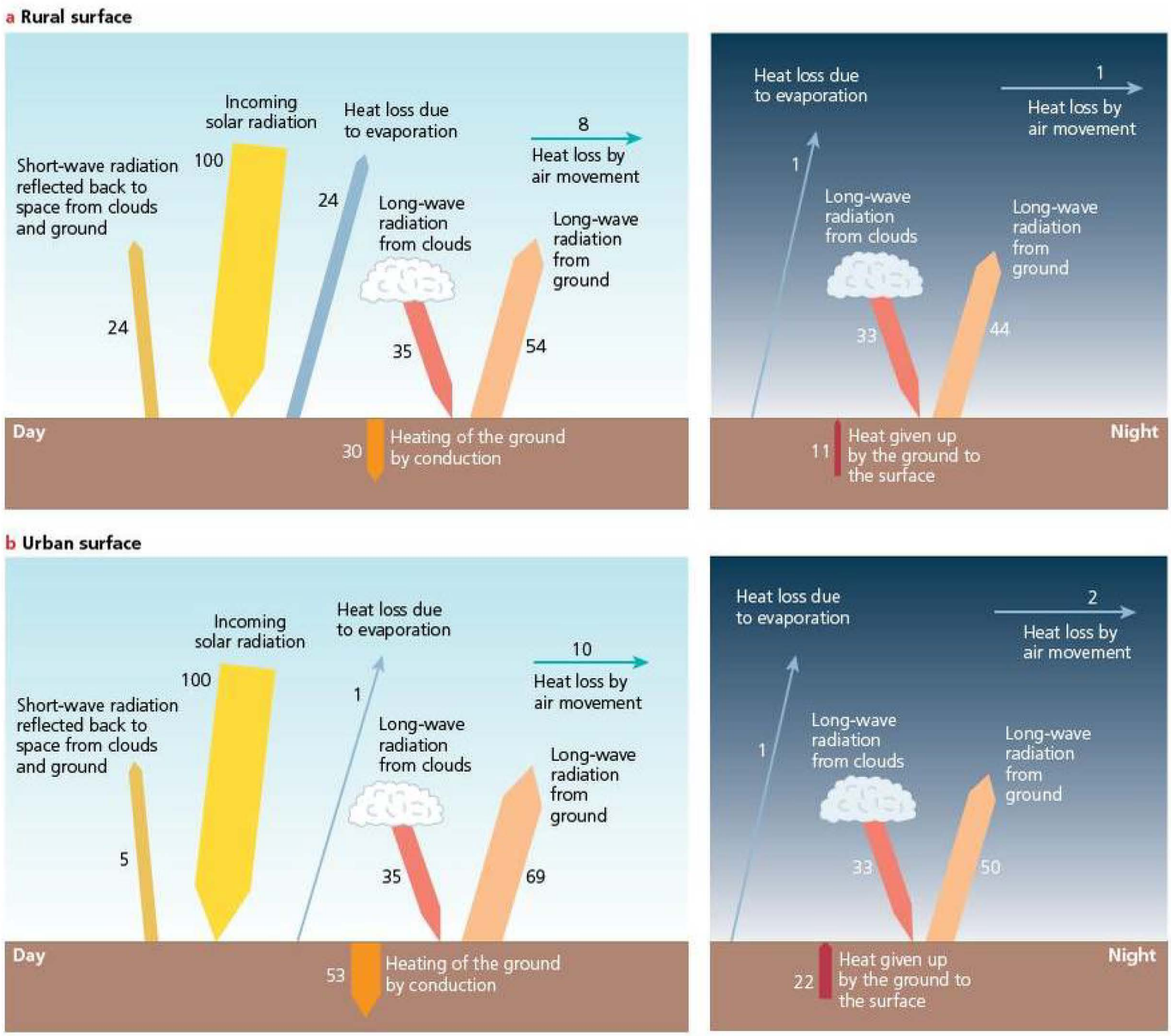
b How does the amount of heat lost through evaporation vary between the areas? Justify your answer.

c Explain the difference between the two areas in terms of short-wave radiation reflected to the atmosphere.

d What are the implications of the answers to **b** and **c** for the heating of the ground by conduction?

e Compare the amount of heat given up by the rural area and the urban area by night. Suggest two reasons for these differences.

f Why is there more long-wave radiation by night from the urban area than from the rural area?



The figures represent the proportions of the original 100 units of incoming solar radiation dispersed in different directions.

Source: University of Oxford, 1989, Entrance examination for Geography

Figure 2.8 Daytime and night-time energy budgets for Washington DC