Chapter 3
Crop Growth Requirements and Climate Control

To check the suitability of a region for protected cultivation, the climate data should be compared with those for other regions and with the main requirements for plants.

3.1 Climate Requirements

Many plants grown in greenhouses are warm-season species. Vegetables and flowers have different climate requirements. The main climate requirements of plant growth can be defined and summarized as follows (Baudoin et al. 1991; Krug et al. 2002; Nisen et al. 1984; Nisen et al. 1990):

1. Plants can be killed by frost. The absolute minimum temperature in the greenhouse has to be above 0°C. The risk of subzero temperatures can be ignored when the daily minimum outside temperature exceeds 7°C.
2. The growth, yield and quality of greenhouse fruit vegetables are affected when temperatures are below 12°C or exceed 30°C (Castilla and Hernandez 2007). Plants grown under protected cultivation are particularly adapted to average temperatures ranging from 17 to 27°C. Optimal temperatures range between 22 and 28°C in the daytime and 15–20°C at night (Castilla and Hernandez 2007). Taking into account the warming-up effect in greenhouses caused by solar radiation, one can define the climatic limits of suitability to be between 12 and 22°C average daily outside temperature if the greenhouses are not heated.
3. The mean absolute maximum temperature for plants should not be higher than 35–40°C. The maximum temperature for a tomato crop should not be higher than 35°C (Verlodt 1999).
4. A minimum of 500–550 h of sunshine for the 3 winter months (November, December and January in the Northern Hemisphere) is desirable. This corresponds to a daily insulation of about 2.3 kWh/m^2 day. The limit for effective production is 1.0 kWh/m^2 day (Krug et al. 2002). Artificial lighting may be used for intensive production.

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5. The minimum threshold for soil temperature is 15°C for heat-requiring plants.
6. Nisen et al. (1990) suggest a threshold of the average night temperature to be 15–18.5°C for heat-requiring plants such as tomato, pepper, cucumber, melon, and beans. The minimum night temperatures depend on the species. Verlodt (1999) gives the following figures
   12°C for hot pepper
   14°C for melon, sweet pepper and eggplant
   7–8°C for strawberry
   The minimum day temperature for a tomato crop should not be lower than 15°C.

   Relative humidity of 70–90% can be regarded being within a safe range.

3.2 Consequences for Greenhouse Construction

The consequences for greenhouse construction and climate control are:

1. If the mean outside temperature is above 7°C, there is no risk of frost. Heating is absolutely necessary if the temperatures fall below 0°C.
2. If the mean minimum outside temperatures are below 10°C in the coldest month, and if the crop needs higher temperatures (cucumber 18°C), heating will be necessary for the improvement of quality and yield.
3. If the mean minimum outside temperature is <12°C (absolute minimum temperature <9–10°C), ventilation openings (ventilators) of greenhouses have to be closed to keep the temperature higher inside. Heating may possibly be necessary.
4. If the mean minimum temperature is >12°C, ventilators can be permanently open. Ventilation becomes necessary if the inside temperature reaches >18–20°C.
5. If the mean maximum temperature is >27°C, ridge or roof ventilation is necessary in a hot and humid climate and for multi-span greenhouses. Evaporative cooling may be recommendable in a dry climate.
6. If the mean maximum outside temperature is >36°C, artificial evaporative cooling is necessary if outside humidity is low enough.
7. If relative humidity at day time is <55–60%, inside humidity should be increased by fog systems or evaporative cooling.

3.3 Measures for Climate Control

The measures for climate control depend on the outside climate conditions. The relationship can be shown by special diagrams showing the influencing factors of global radiation, mean minimum temperature, mean maximum temperature, and humidity.

3.4 Tropical Regions

As the temperatures depend on altitude as well as on latitude, different greenhouse constructions have to be designed for tropical lowlands and tropical highlands (see Chap. 5).

The main characteristic design criterion is the mean minimum outside temperature, depending on altitude and latitude.

Greenhouses for tropical highlands with mean minimum temperatures below 12°C have to have ventilation openings that can be closed.

Greenhouses for tropical lowlands with mean minimum temperatures above 12°C can be permanently open at side walls and ridge ventilators throughout the year.

The climate conditions can be very different even in the same country, so different greenhouse constructions have to be considered. That means the local climate conditions should be considered for successful site selection.

The following figures show the dependence of mean minimum versus mean maximum temperatures in tropical regions:

Karonga (Malawi) has mean minimum temperatures above 15°C and mean maximum temperatures lower than 33°C. Greenhouse constructions with permanently open ventilators are suitable. Lilongwe (Malawi) has mean minimum temperatures below 12°C. Greenhouses have to have vents that can be closed at night, and very good ventilation efficiency by ridge ventilation in the daytime for crop production throughout the year. Almeria in the Mediterranean region (subtropics) has similar conditions, but in many cases there is no production in July and August (Figs. 3.1 and 3.2).

The temperatures in Bangalore (India) at an altitude of 921 m are higher than in Pune (India) at an altitude of 560 m. The reason is the lower latitude of Bangalore. Greenhouses in Pune should have closable ventilators, while ventilators of greenhouses in Bangalore can be permanently open. That means both the altitude and latitude have to be considered for decisions on greenhouse construction (Fig. 3.2).

The mean daily global radiation is above 4 kWh/m^2 day throughout the year in Lilongwe (highlands) and Karonga (lakeshore plain, Malawi) as well as in Bangalore and Delhi (India) (Fig. 3.4). Mean maximum daily global radiation is not much higher than 7–7.5 kWh/m^2 day in tropical regions. Solar radiation may be too high around noon in some months, as the day length is relatively short. Shading may be necessary for some crops. The construction and cladding material cause a reduction of incoming light by about 20%, and the shading effect is increased by dirt deposition on the plastic film (Fig. 3.5).

The mean humidity is higher than 80% for some months in Karonga and Lilongwe when precipitation is highest (Fig. 3.6). These are months with mean outside temperatures below 30°C. The humidity is relatively low in months with higher temperatures. Evaporative cooling as well as fog systems may possibly be necessary for flower crops.

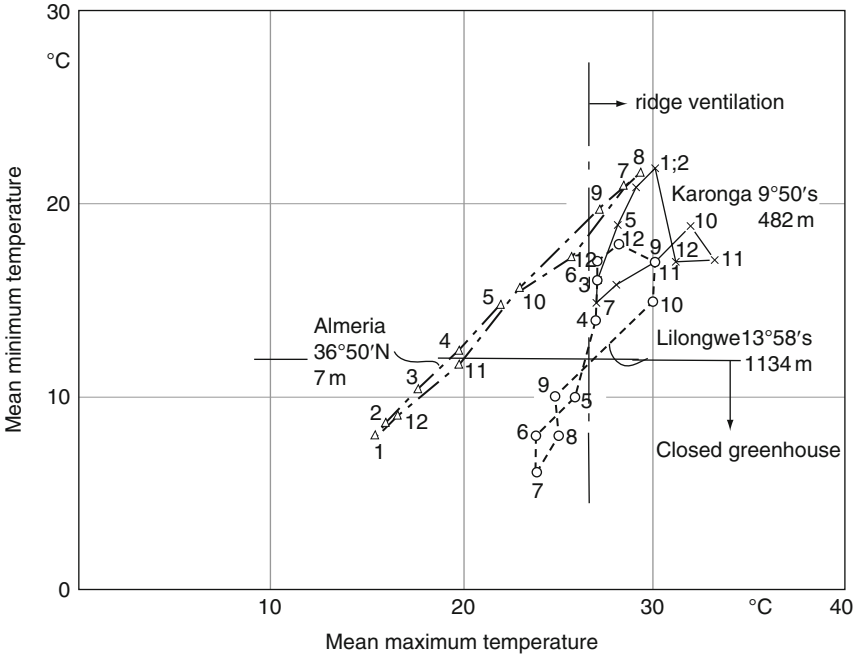

Fig. 3.1 The mean minimum temperatures versus the mean maximum temperatures for Karonga (lakeshore plain) and Lilongwe (Highland) in Malawi from January (1) to December (12), in comparison to the subtropical region of Almeria (Spain)

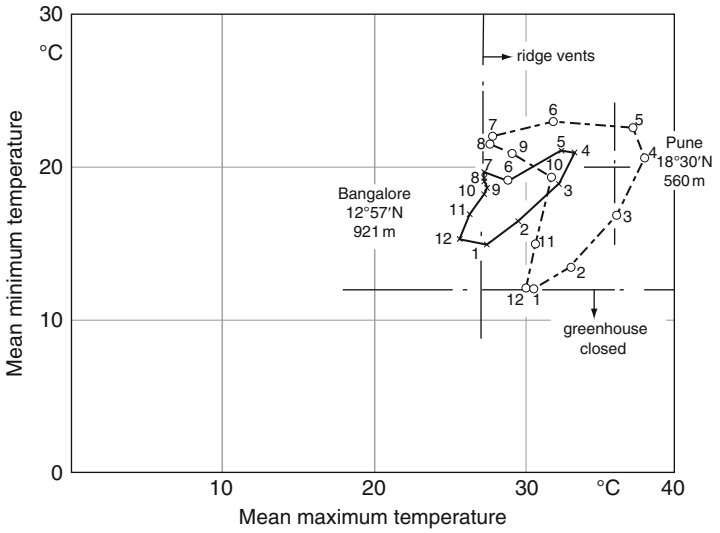

Fig. 3.2 Mean minimum and maximum temperatures for Bangalore and Pune (India)

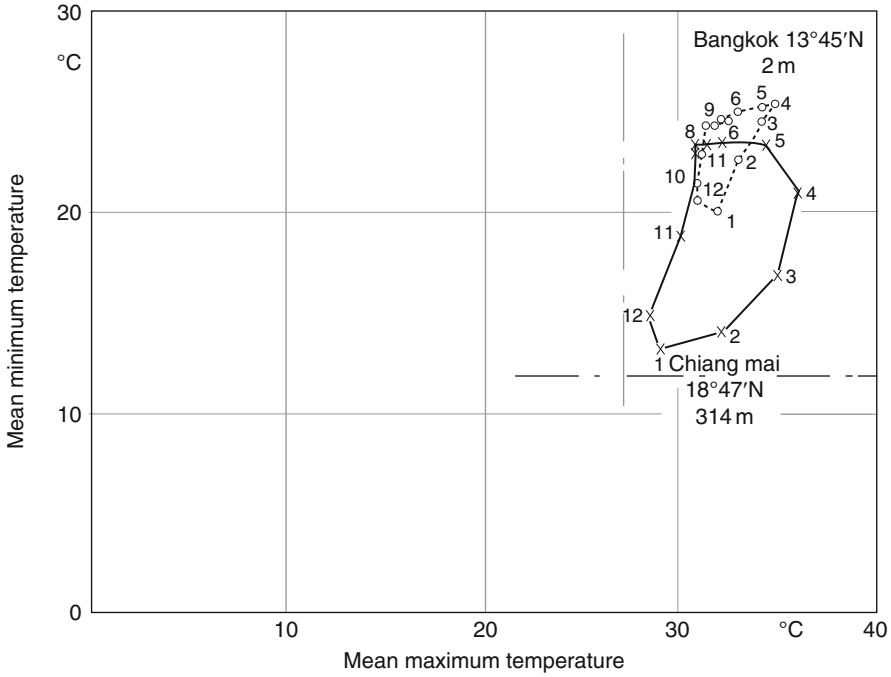

Fig. 3.3 Mean minimum and maximum temperatures for Bangkok and Chiangmai (Thailand). Both locations have suitable temperatures for crop production in greenhouses if ridge vents are installed

3.5 Subtropical Regions

The maximum temperatures in subtropical regions (Mediterranean) are high in summer and the minimum temperatures below 10°C in winter (Fig. 3.7).

Heating may be necessary for successful crop production in both regions for some months in winter. It becomes very hot in summer in Antalya, so ridge vents are necessary in multi-span greenhouses. Possibly evaporative cooling may be necessary. Greenhouses for vegetables are normally out of production in summer months.

Figure 3.8 shows the precipitation for Antalya and Almeria, in addition to the temperatures. Almeria is a very dry area with low precipitation in winter and summer. Antalya has high precipitation, in particular in winter. Gutters are necessary for greenhouses in Antalya to lead off the rainwater and to protect crops from water penetrating through the side walls. Collecting of rainwater for irrigation is recommendable and profitable in Antalya. Greenhouses in Antalya need more ventilation efficiency in spring, summer and autumn.

A typical greenhouse type for Almeria, the Parral type, is not transferable without problems to Antalya or other Mediterranean regions.

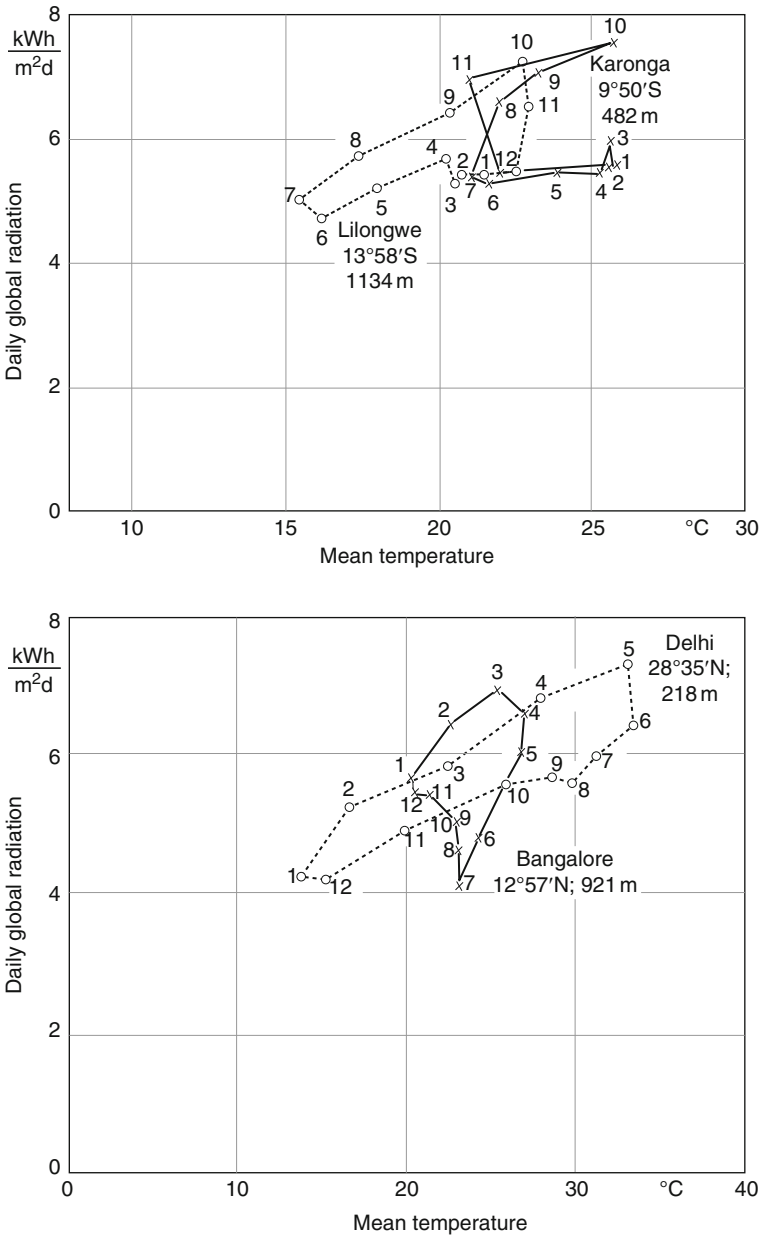

Fig. 3.4 Mean daily global radiation versus mean temperature in some tropical locations

The subtropical climate near the Mediterranean Sea is much more suitable for crop production in greenhouses than the more continental climate in Delhi. Greenhouses have to be heated in the highlands of Kashmir during winter and very well-ventilated in summer (Fig. 3.9).

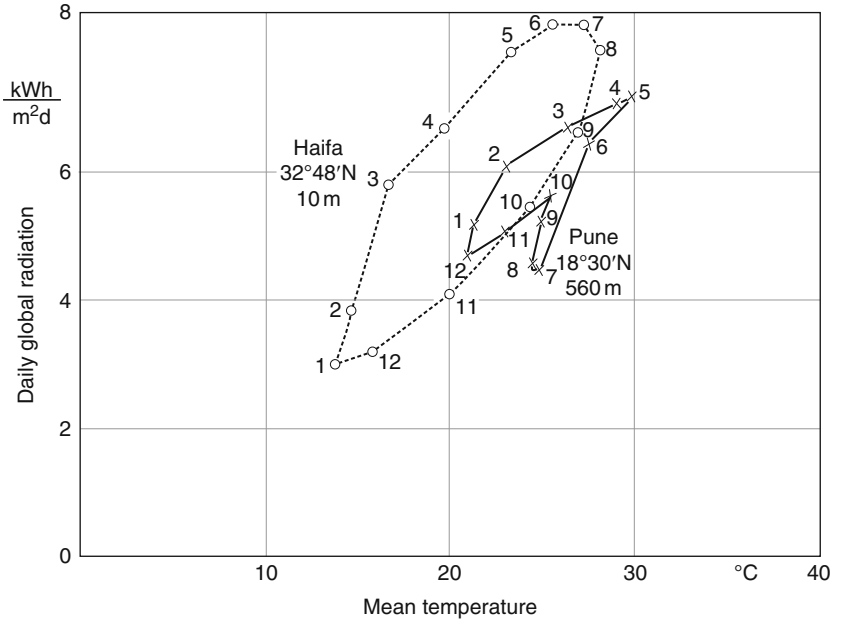

Fig. 3.5 Mean daily global radiation versus mean temperature for Haifa (subtropics in comparison to Pune (tropics). Haifa (subtropics) has, in comparison to Pune (tropics), very high global radiation in summer and values below 4 kWh/m^2 day in winter

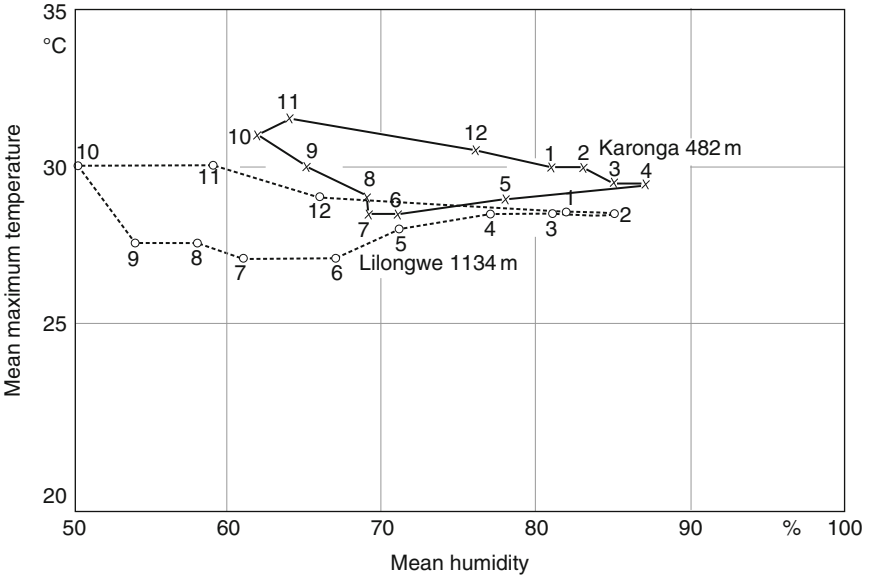

Fig. 3.6 Mean maximum temperature versus mean relative humidity for tropical locations in Malawi

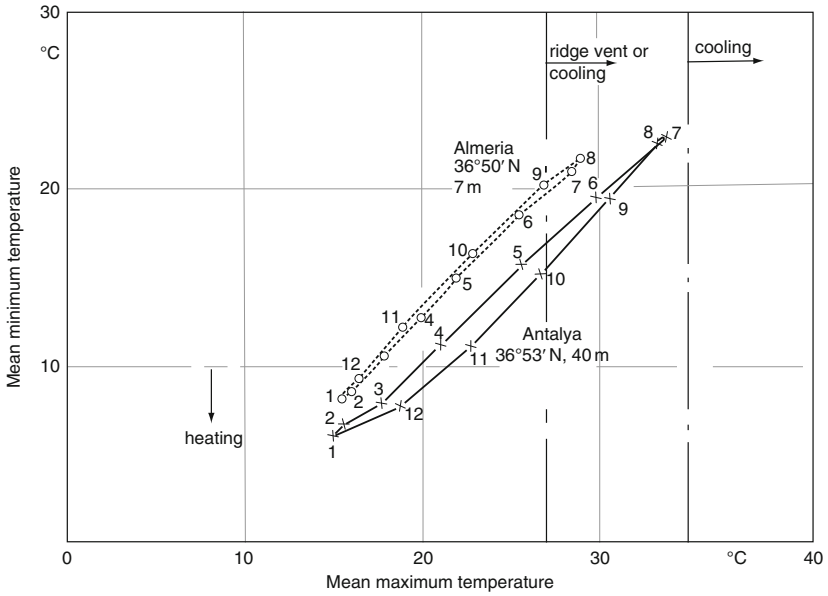

Fig. 3.7 Mean maximum and minimum temperatures for subtropical sites in Almeria (Spain) and Antalya (Turkey), both on the Mediterranean, where large areas of greenhouses are located on the Northern Mediterranean sea coast

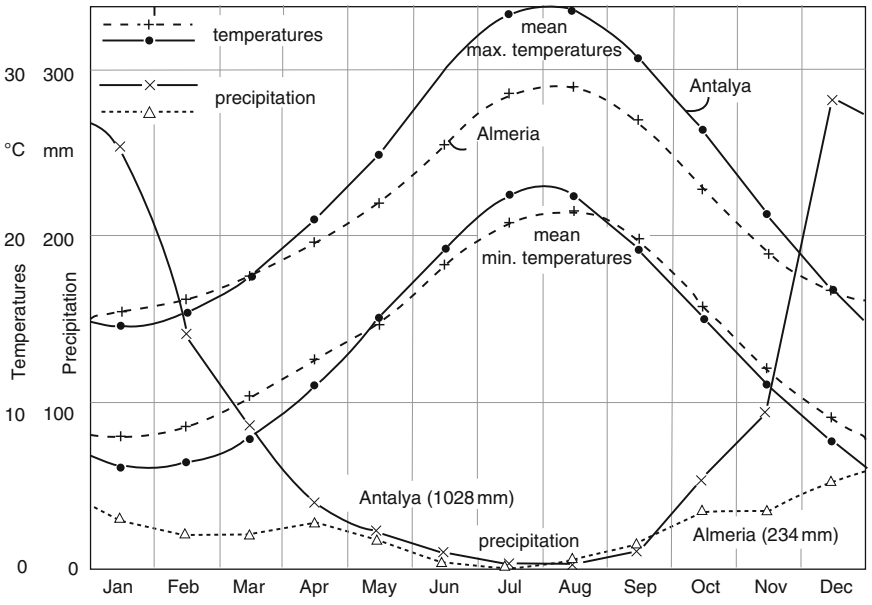

Fig. 3.8 Precipitation and temperatures for Almeria and Antalya

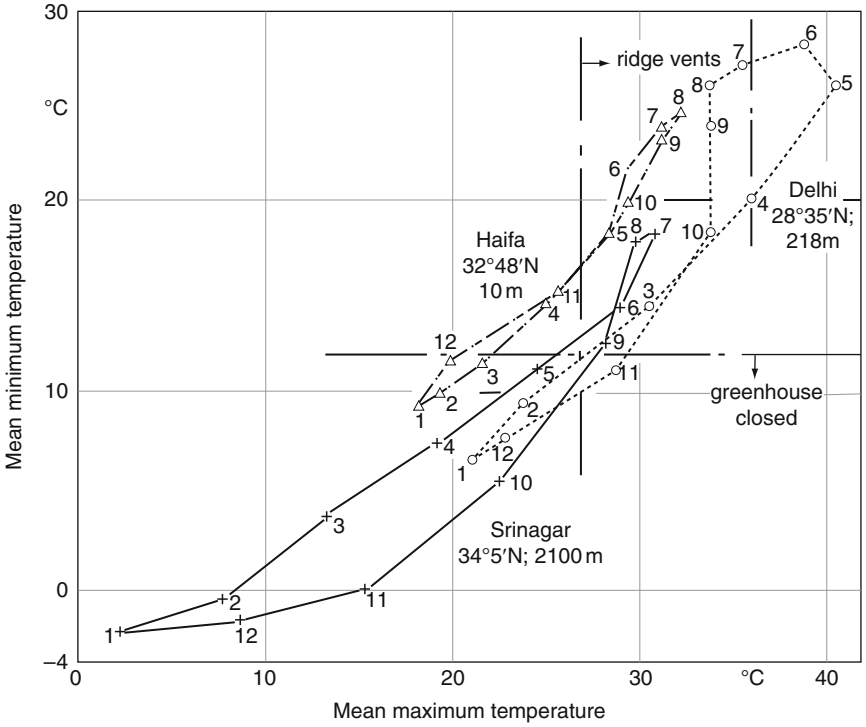

Fig. 3.9 Minimum and maximum temperatures for Haifa (Mediterranean) in comparison to Delhi (India) and Srinagar (highlands of Kashmir, India)

The coastal climate in Lebanon (Beirut) also fits the conditions for protected cultivation more than in Aleppo (Syria) with more arid climate (Fig. A.1 in Annex 1). Cooling and heating is necessary for year-round cultivation in Aleppo.

Large greenhouse areas are located in the region of Agadir (Morocco), where the climate is suitable for protected cultivation. Some heating may be necessary in winter. Cairo (Egypt) also has some cold winter days and very hot summers (Fig. A.2). Jixi County in central China, with a continental climate, has unsuitable temperatures compared to Cairo at the same latitude, both in winter and in summer (Fig. A.3).

Figure A.4 shows the climates of Famagusta (Cyprus) and Catania (Sicily). Both islands are well-known for protected cultivation.

Figure 3.10 shows the mean daily global radiation versus the mean daily temperature for Almeria and Antalya (subtropics) in comparison to a temperate climate in De Bilt (Netherlands). If the mean daily global radiation is considered to be 2.3 kWh/m^2 day, the Antalya region has not enough light in December and January. There is lower global radiation but higher mean temperatures in Antalya than in summer in Almeria. In both centres, crop production is difficult

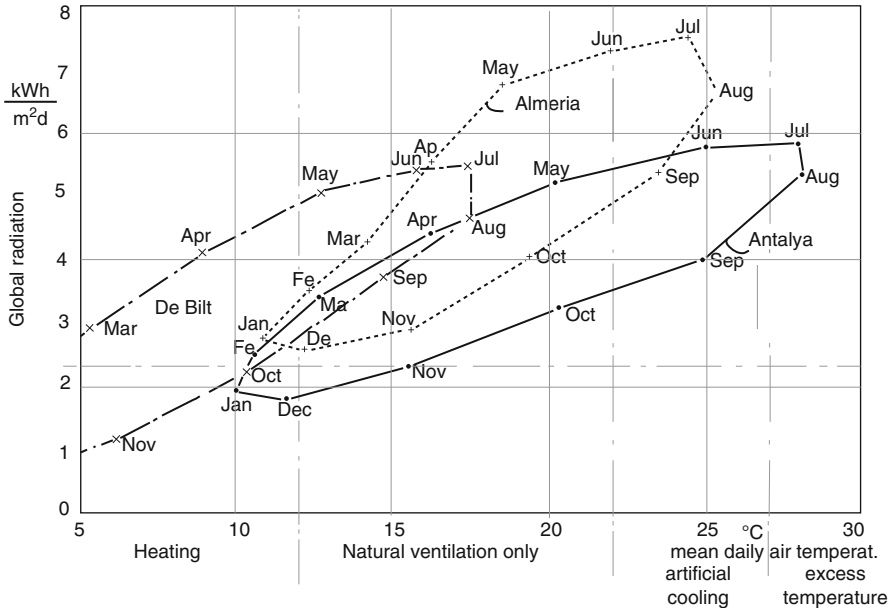

Fig. 3.10 Mean daily global radiation versus mean temperature for Mediterranean sites in comparison to temperate climate in Netherlands

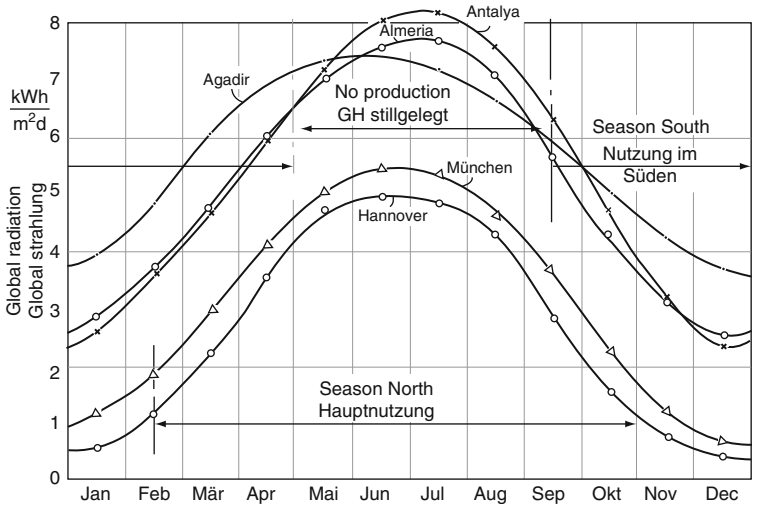

Fig. 3.11 Mean global radiation in subtropical (Mediterranean) sites compared to temperate climates (Germany)

without artificial cooling in summer, but most of the greenhouses are out of production during this period.

Figure A.5 shows the global radiation for Agadir (Morocco) and Gafsa (South Tunisia) compared to Almeria (Spain).

The mean daily global radiation in subtropical climates (Agadir, Almeria and Antalya) is higher than in the temperate zones (Hannover, Munich, Germany) (Fig. 3.11). But one has to take into consideration the main cropping seasons, for vegetables in particular. Transplanting starts in September/October in the Mediterranean, and the plants grow and develop with decreasing light intensity up to the middle

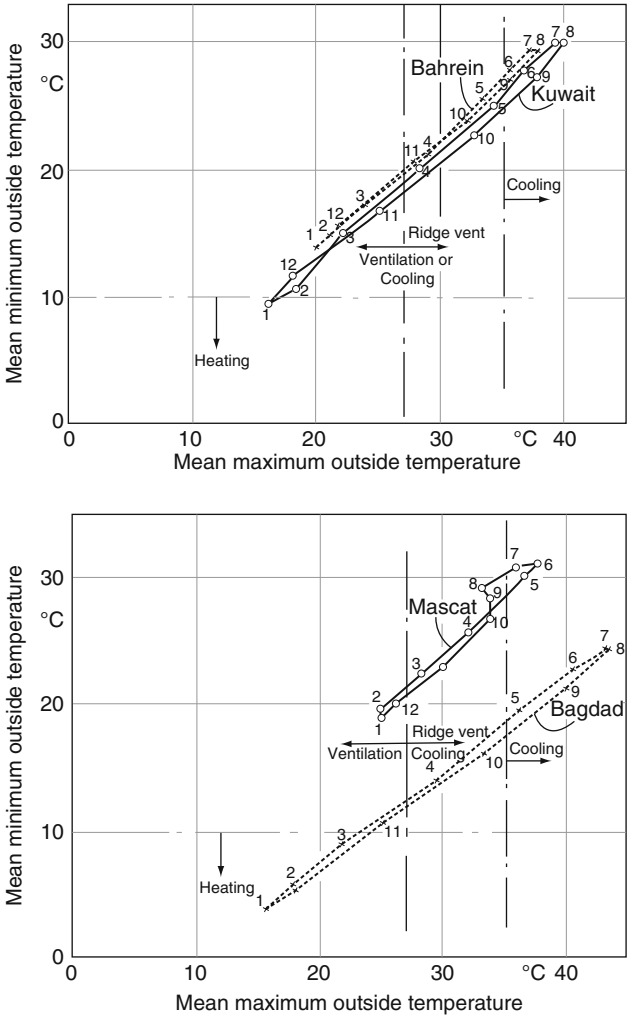

Fig. 3.12 Mean minimum outside temperature versus mean maximum temperature for some sites in arid regions

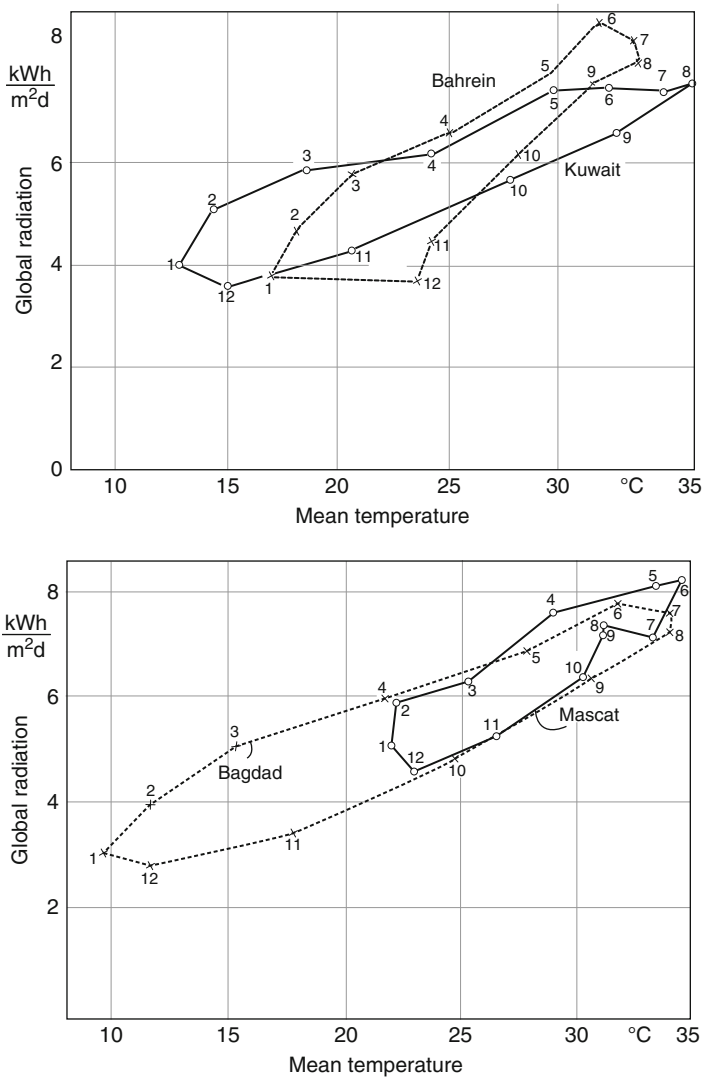

Fig. 3.13 Mean daily global radiation versus mean temperature for arid regions

of the cropping season, when light intensity is at a minimum. Transplanting in the Northern countries (temperate climate) starts in February, and crops grow with increasing light intensity by a maximum in the middle of the season. As light is a limiting factor during the growing season in southern subtropical countries, one has to increase light transmittance of greenhouses as much as possible for vegetable crops.

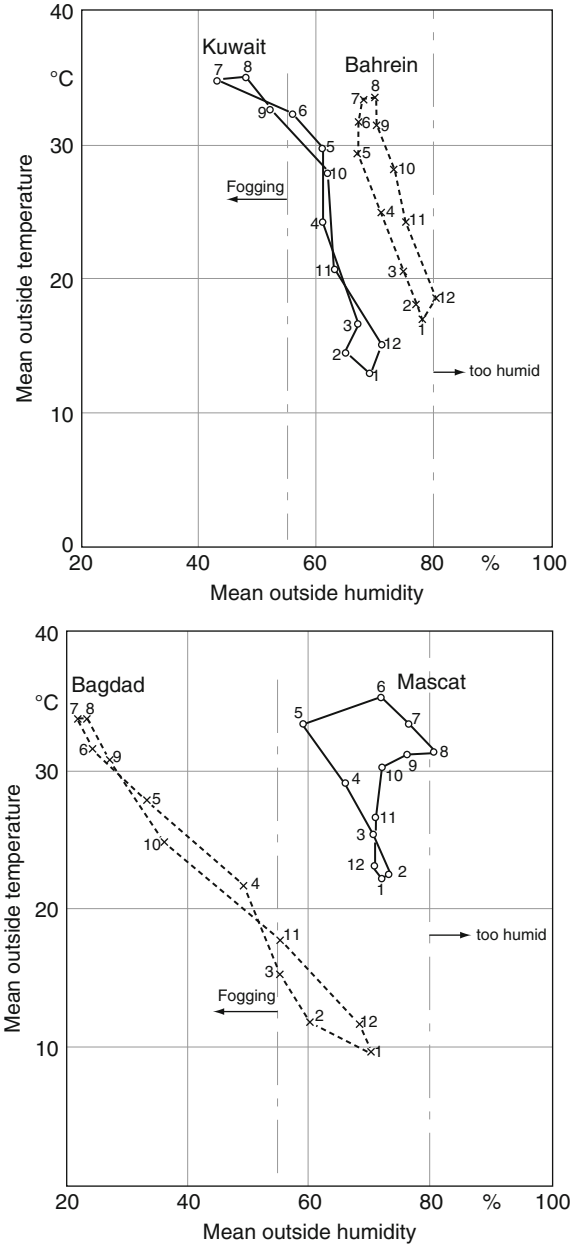

Fig. 3.14 Mean outside temperature versus mean outside humidity for arid regions

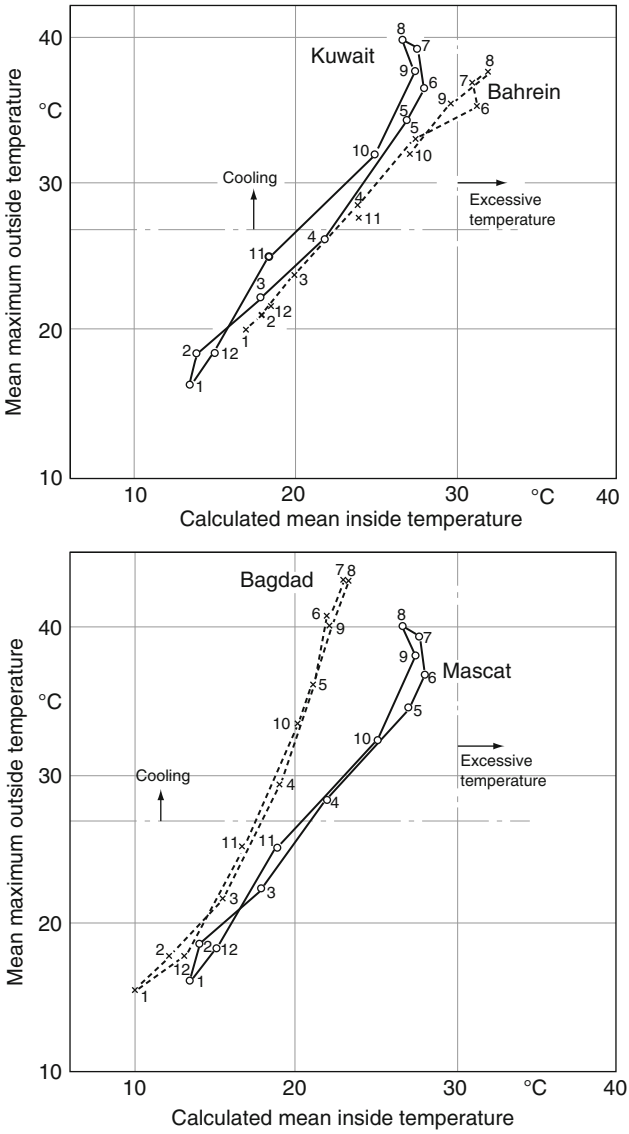

Fig. 3.15 Mean maximum outside temperature versus the calculated mean inside temperature for arid regions that can be achieved by evaporative cooling

3.6 Arid Regions

Figure 3.12 shows the mean minimum outside temperature plotted against the mean maximum outside temperature for different places in arid regions (Bahrein, Kuwait City, Bagdad and Mascat).

If evaporative cooling is necessary with average maximum outside temperatures of more than 27°C, and if heating at night is necessary with average minimum temperatures less than 10°C, evaporative cooling is necessary from April to November in Kuwait, Bahrein and Bagdad and from March to December in Mascat. Multi-span greenhouses should have forced or roof ventilation.

Heating at night may be necessary in Kuwait and Bagdad. Mascat and Bahrein need no heating, perhaps only emergency heating for some cold nights.

Figure 3.13 shows mean daily global radiation plotted against mean daily temperature:

- The minimum global radiation is higher than 2.5 kWh/m^2 day at all places, which is enough for plant production in winter.
- Global radiation is very high during summer months; shading may be necessary.
- The average temperature exceeds 30°C in all countries.

Figure 3.14 shows the mean outside temperature plotted against the mean outside humidity. If evaporative cooling is necessary during summer from April to November, the outside humidity has to be low enough for the cooling.

The average humidity in Kuwait is below 70% throughout the year. Bahrein has an average humidity below 75% from July to September, and evaporative cooling may be inefficient. Cooling in Bagdad is no problem in summer. Mascat has high humidity during summer, and cooling is difficult.

Figure 3.15 shows the mean maximum outside temperature plotted against the *calculated* mean minimum inside temperature which can be achieved with evaporative cooling.

The calculation was done with the average outside temperature, the average outside humidity and the average maximum outside temperature in Mollier's h–x diagram. The assumption was a constant water content with rising temperature from average temperature to average maximum temperature. If the average minimum inside temperature is assumed to be not higher than 30°C, evaporative cooling may be difficult from June to August in Bahrein. Greenhouses in the other climate zones can be cooled during summer.