Temperature gradients in greenhouses

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Greenhouse heating aims at creating optimal growing conditions for plants. But if heating is done inadequately, the plants will do less well and energy will be wasted. Ideally, all plants in the greenhouse grow at the same temperature, and have a nice even temperature from top to toe. But in most greenhouses we find temperature differences, or 'temperature gradients', both in horizontal and vertical directions. For instance we see hot and cold spots, or hot feet and cold heads.
Hot spots indicate that too much heat is delivered on one place, which is just a waste of energy. Moreover, a consequence of hot spots is that cold spots are created elsewhere. Cold spots are notorious cradles of diseases and pests. Horizontal temperature differences are undesirable for all these reasons. The best ways to overcome the problem is by finding the cause and rectifying what is wrong.

Hot & cold spots

A hot spot may not seem to be a problem, but it is. Note that we are talking about winter conditions, when heating is needed. Warm air is lighter than cold air, so warm air rises. On a hot spot the warm air flows upwards and then along the roof, where it looses its heat. The (now cold) air comes down somewhere else, and creates a cold spot. From the cold spot, air will flow over the floor to the hot spot. This air flow can take the form of an unwanted draught.
On cold spots, plants grow slower, stay smaller and flower later than on warm spots. Plants on a cold spot will take up less water and thus the slabs or bags will be wetter. Moreover, cold spots are moist: places with 1 °C lower temperature have a 5% higher relative humidity. At times of high air humidity these cold spots are the first places where condensation occurs. If these plants get wet (and they are already weak) they will be the first to get fungal diseases such as grey mould (Botrytis) or a pest.

Causes of horizontal temperature gradients

Horizontal temperature gradients can be due to a number of factors. The first is that a certain section of the greenhouse receives a different amount of heat. An example is when overhead hot-air heaters are used: the area in front of a hot air heater will be warmer than areas outside the heater's pathway. Uneven temperature can also occur with pipe heating, for instance when the boiler or the manifold is located inside the greenhouse, or if a hot transport pipe runs through the greenhouse. The heat source heats up the nearby plants, whereas the plants further away will stay relatively cold.
To overcome the latter, the transport pipe can be insulated. A boiler should never be located inside the greenhouse in the first place. This is not only because it causes hot spots, but also because of the risks of gas leaks or flue gas leaks that may damage the plants.

Flaws in the heating system

With pipe heating, many things can cause horizontal temperature differences. For instance it is possible that the front half of the greenhouse is connected to one transport pipe, and the back part to another transport pipe. The two transport pipes may be different in flow rate or water temperature, and hence deliver different amounts of heat. This is often found in greenhouses that were built in two stages.
It also happens that one section of the greenhouse contains more heating pipes per bay than another section. Or that the pipes in one section of the greenhouse are ticker (have more surface area) than in another. Or that pipes are made of different materials. Less heat is emitted by galvanised pipes, or rusted pipes or pipes that are painted with aluminium paint.

It is also possible that a pipe is partly blocked at the point where it is welded to the supply pipe or return pipe. A difference of 2-3 °C in pipe temperature can cause 1 °C difference in air temperature. All the above can cause uneven air temperatures in a greenhouse.
The lay-out of the pipe heating system is very important too. Modern heating systems should have the Tichelmann lay-out. This means that the supply pipe gets thinner in diameter towards the end, while the return pipe becomes thicker towards the end of the greenhouse. This warrants equal flow speeds in the heating pipes. In older greenhouses, the heating systems are sometimes not built according to Tichelmann, which then explains the uneven temperature.

Other causes
There are several other possible causes of horizontal temperature gradients. A notorious one is a sloping ground level. Warm air rises and cold air travels to the lowest point, causing a systematic difference in air temperature.
Horizontal temperature gradients can also be caused by leakage of greenhouse air through broken windows, or through windows that don't close properly. In a greenhouse that was built in two stages we often see different types of vents in the two parts of the greenhouse. It is possible that one vent type leaks more than the other type, and therefore one section will be colder in winter. This causes a circulating airflow: warm air flows along the roof and cold air along the ground. The warm air flow along the roof looses energy.
The use of a thermal screen (energy screen) can cause temperature gradients too. If the whole greenhouse is screened, the heating pipes will run at a lower temperature. However, if the walls are not screened, the temperature will go down there due to the lower pipe temperature. Since the heating pipes are colder with the screen closed, the plants along the walls miss out on heating. We find that the section along the whole wall can be one long cold spot.
Wind can cause air movement, which may cause temperature gradients. However, in most cases air movement helps reducing differences in air temperature.

Vertical temperature gradient
A vertical temperature gradient means that the temperature is different at various heights: for instance cold feet and a warm head (if heating is overhead) or warm feet and cold head (if heating is below the plants). Vertical temperature gradients also happen due to the weather conditions: at night the top of the plants is often relatively cold, and on sunny days the leaves in the sun are relatively warm, sometimes even by 5 °C. A vertical temperature gradient is not necessarily bad; sometimes it even has a positive effect. For instance if fruit are warmer than the rest of the plants they attract more assimilates, and ripen quicker.
A vertical temperature gradient can be a problem sometimes. If the roots are warm, they are active and pump up a lot of water. But when the top of the plant is cold, it evaporates little water. This can cause 'guttation', which is when droplets come out of the edge of the leaves. It can cause damage to the leave edges. This happens especially when the humidity is high, for instance early in the morning.
In contrast, cold roots don't take up water easily. If meanwhile the head is warm, water evaporates from the head. This can cause wilting in the top of the plant. Transpiration, growth and development are best when the whole plant is at reasonably similar temperature.

Horizontal air fans (HAFs)
Once the cause of the temperature gradient has been determined, it is a matter of trying to rectify it. This may require some welding or other work on the heating system. Sometimes simple things will be sufficient, for example, if some pipes give off too much heat, it helps to paint them with aluminium paint. Rectification the problem will cost money and effort, but the benefits of improved growing conditions and reduced energy loss may be worth it.
Only if everything else fails, one should consider installing horizontal air flow fans (HAFs) to stir the air around. Fans can be helpful as a last resort in hard cases where the temperature is uneven. HAFs costs energy: firstly they use electricity, but secondly they move warm air along the roof where the warm air looses energy. There is quite a bit of knowledge on how these HAFS need to be positioned to be most effective. A future article will go deeper into proper installation of HAFs. The next one will discuss how to measure temperature gradients.

Energy advice

If you want to find the cause of temperature gradients or other points of improving your heating system, you may need an energy audit done by a specialised consultant. He can show you shortcomings, discus options for improvement, or explain the settings in the climate control especially for humidity control. Some hours of advice by a specialist can save some % on your energy bill. Even if it was only 1%, it can still be worthwhile.

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