Measuring temperature gradients in greenhouses

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Most greenhouses will have an uneven temperature pattern or 'temperature gradient', especially in winter. This means there are cold and hot spots, which can costs tens of thousands of dollars per hectare due to reduced production, diseases and waste of energy. The previous article in this series explained what causes these temperature gradients. In winter it is mostly due to flaws in the heating system or uneven vent opening. The present article discusses how to measure temperature gradients.

Temperature gradients cost money

The heat distribution in a greenhouse is often uneven: too much heat is delivered on one place, and less on another place. On a warm place, the hot air rises and flows along the roof. Here the air looses its heat, and the (then cold) air comes down on another place, where it creates a cold spot. This causes an ongoing air circulation: cold air along the ground, and warm air along the roof. This costs energy.

Moreover, cold spots are more humid: 1 °C lower temperature causes 5% higher relative humidity. Plants on cold spot grow slower and are productive than plants on warm places. Moreover, these plants are the first to get wet from condensation under high humidity conditions. Hence they easily get diseases and pests, which can then spread through the greenhouse. This all costs money.

Climate control aims at avoiding high humidity. In fact the humidity level to avoid is 95 or 98%, but a large safety margin is built in so that no condensation occurs on even the coldest spot. Therefore most growers set their humidity controller on 80% or even lower. This is a large safety margin! If there were no cold spots, the margin could be smaller, and far less energy would be needed for humidity control. In greenhouses that are known to have an even temperature distribution, it is safe to aim for 85% or 88% or even higher, instead of 80%.

Testing the thermometer

Measurements can be done to find out if there is a temperature gradient or how serious the problem is. You can use a whole lot of little data-loggers that measure and record the temperature. That is by far the easiest method, but has a cost. You can also measure the temperature gradient with one good thermometer. This must be digital, accurate, consistent and fast enough. It must show one decimal: so you can read 19.9 or 20.1 °C, not just 20 °C. First test the consistency and speed of the thermometer. Use two large bowls or bottles filled with water, one of about 15 °C and the other of about 30 °C. Measure one bowl and see how long it takes to get a stable reading. Measure the other bowl, and wait for a stable reading. Back to the first bowl, and see if the reading is the same as the first time. Again to the other bowl to see if that reading is the same as before. Repeat this a few times. If the thermometer does not get back to the same reading, or if it takes an awful long time to produce a reading, then this thermometer is not useful for this purpose. Get another one. This test also tells you how long you need to measure in one measuring point to get a reliable reading.

Measuring in the growing media

Reliably measuring air temperature is hard because it fluctuates a lot. A way around it, is measuring the temperature of water instead of air. Water temperature changes slowly, and is therefore a good reflection of the air temperature in the previous hours.

Water in the growing media can be used quite well as an indication of air temperature, except if the slabs have uneven wetness (e.g. in a young crop), or if the slabs are heated. The temperature measurements must be done before the irrigation starts. Do the measurements by sticking the thermometer in the growing media at a standard depth that you choose (e.g. 30 mm). Use a standard location, e.g. in the middle of two plants. First do a number of test measurements. Stick the thermometer in the growing media a few meters apart from each other, where you expect the same air temperature (all at the same distance from heating pipes). If the readings are similar, the method is reliable. If not, investigate why it doesn't work well in this case. See if you can improve the measurements by choosing more similar measuring points, or another measuring depth.

Measuring in bottles

Alternatively, the temperature can be measured in bottles filled with water. They are purposely placed on selected places throughout the greenhouse. It is more work, but gives the most accurate results. It does not matter if the bottles are glass or plastic: beer bottles or larger soft-drink bottles can be used. All bottles have to be filled with the same amount of water, hung at the same height, and at the same distance from the heating pipes. The easiest place is at eye-height. If the temperature readings are done during the day, the bottles can warm up due to sunshine. To avoid this, the bottles should be wrapped with aluminium foil.

Conditions

Cold spots and hot spots will be mostly on the same location, but can be more obvious under particular conditions. The best measuring results are achieved on a cold day when the heating pipes are hot. In principle, the measurements must be done under stable conditions. There should be no changes in heating pipe temperature, vent opening and energy screens (if present). Preferably you measure early in the morning before the heating system goes to the day-time settings. The measurements should be finished before the sun becomes too strong (say 75 Watt/m2).

On the other hand, the water temperature lags behind, so it is possible to do measurements under changing conditions. However, in that case, re-do the first measurements after all measurements are finished. If you get the same reading in the first measuring points as you had before (or less than 0.3 degrees different) it can be assumed that all measurements are still valid. If it has changed too much, you decide either to discard all measurements, or use them as they are, or apply a correction.

On each measurement sheet, write down the date and the conditions such as weather, wind speed and direction, temperature and humidity and set points in the greenhouse, vents opening, fans on or off, screen open or closed, etc. Repeat the measurements on other days with the same conditions, to confirm the reliability of the measurements. You can then do the measurements on days with different conditions, to investigate the effect of those conditions.

Drawing a site plan

Before doing any measurement, the first step is drawing a plan of the greenhouse. This should show all relevant features: entrance, main path, boiler (if located in the greenhouse), heating nets (if there is more than one net), heat transport pipes, hot air heaters (if any), fans (if any), venting groups (if there is more than one group of vents), measuring box, special insulation, energy screen (if any), etc. You can draw the greenhouse on quad paper, with every square covering one span and one section between poles.

Then you mark the places where you plan to measure the temperature. A good number is between 40 and 60 measurements on 1 hectare greenhouse. The influence of the wall is best measured about 1.5 m away from the wall. Same with the main path: chose the measure points 1.5 m away from the main path. The other measure points are placed in between, roughly 20 to 30 meters apart. Also place some measuring points close to the measure box and near other interesting features.

Make a few photocopies of this greenhouse plan when it is blank, so that you can use it for recording temperature measurements on various days.

Measuring temperature gradients
Go round along all measuring points in a systematic way, and stick the thermometer in the water (in the bottles or growing media). Wait until the reading is stable (the time needed depends on the type of thermometer). If the reading is stable, record the measured temperature on the greenhouse plan on the appropriate location. It can take up to about an hour in a one-hectare greenhouse. After finishing all measurements, go back to the first measuring point and check if the temperature has changed. If it has changed not more than 0.3 °C, it is fine (see above).

Drawing temperature patterns
If the measurements are all recorded on the greenhouse plan, one can visualise the results by drawing lines and adding colours. Try to draw a continuous line that connects places with the same temperature. For instance you want to draw the 18-degree line. This means that on one side of the line it was above 18 °C, and on the other side it was below 18 °C. Of course the water temperature measurement was often not exactly 18 °C. But you found for instance that one measuring point was 17.5 °C and the next one was 18.5 °C. Exactly in the middle of these two points we assume it was 18 °C. So the 18-degrees line goes through this point. We do the same for the 19-degrees line, 20-degrees line, etc. You may find there are little islands where the temperature is very high (let's say over 21 °C) and other little islands where the temperature was very low (let's say below 17 °C). Larger areas will be 19 °C. You can give them different colours: the coldest places are dark blue, medium temperature are light blue, white or light pink, and the warmest places are coloured red. You will find a similar pattern nearly every day, with some small variations.

Resolving any problem
Once you have localised the cold and hot spots, you can search for an explanation. The previous article described possible flaws in the heating system and venting system. Some things can be resolved fairly easily. For instance, a transport pipe can be insulated. If one greenhouse has two heating or venting sections, it may help to change some settings in the control computer.
The use of fans (HAFs, or horizontal air flow fans) is not always the best solution to resolve an uneven temperature, as mentioned in the previous article. Fans cost money (investments, electricity) and waste energy (by blowing hot air against the roof). But if nothing else can be done, fans can be installed as a last resort.

Investigating particular effects
The measurements on temperature gradients as described above can be used to investigate the effect of a certain action. For instance, if you have a thermal screen, you can see how the temperature pattern differs between a day with closed screen and a day with open screen. If you have made changes to the heating system to resolve a problem, or have installed fans, you can see if these actions have the required effect. Also you can see whether the fans are on the right place. Please note that it is important where fans are placed in the greenhouse, as will be discussed in the following article.

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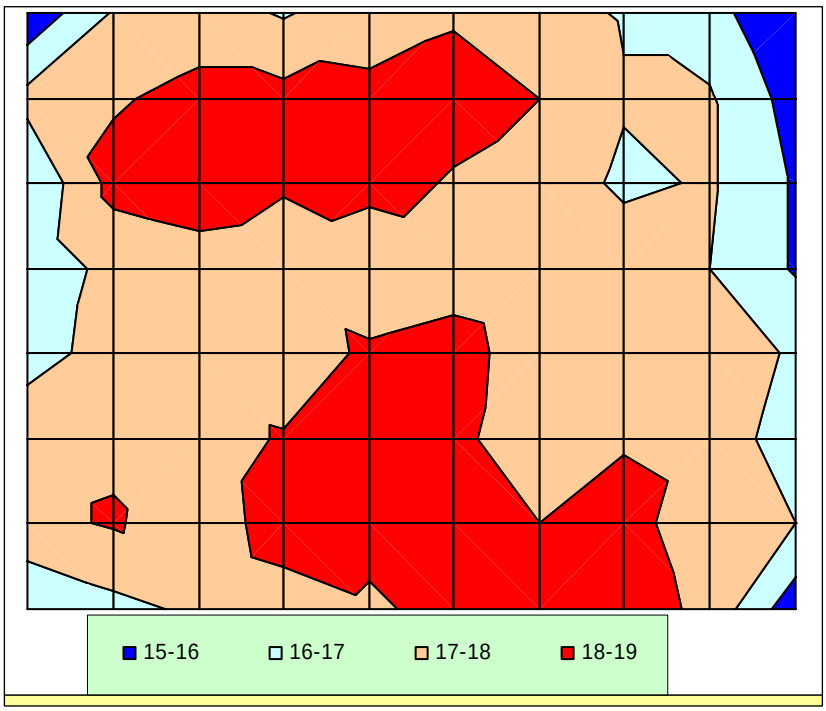

Figure: *Example of temperature gradient in a greenhouse. Here the lowest temperatures are found along the walls.*