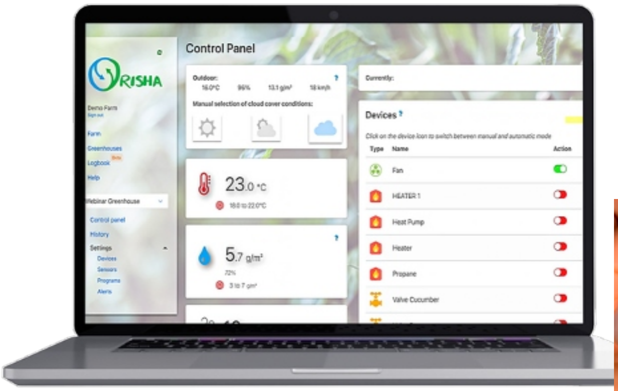
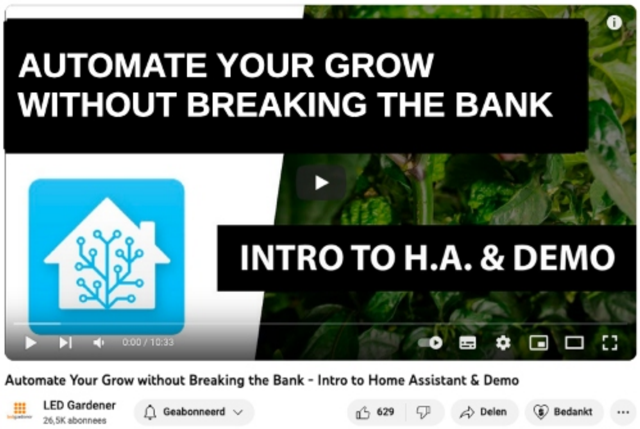
Measuring and controlling with sensors in the garden

for small to medium sized gardens and focussed on low-cost solutions





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Last update: 2024/08/02
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Location: digital version of this document

This report can be downloaded at https://johanf44.github.io/moestuin-dh/.
Alternate link: https://github.com/johanf44/moestuin-dh

If this document is revised, the new version will also be published at that location.

Translation errors may occur

Originally this document was written in the Dutch language as the author is from the Netherlands. To also offer the information to readers from other countries, the document has been translated by a software translation application to an English written version. The text has not been meticulously proofread, so it may occasionally contain some strangely formed sentences.

Source reference within the text

Various sources have been used for this report. Within the text, these sources are referenced with a number in superscript above a word, such as: text[5]. This number refers to the source in the chapter References on page 84.

There are also many links to sources included in the text. When reading this report on paper, it is useful to also have the digital pdf version at hand, so that it is easy to click on the links and visit them if desired.

The text sometimes includes 'thumbnails' of videos on YouTube with more information. These videos are not included in the reference list, as they are already so clearly referenced in the text.

Sources images on cover

See the References on page 84, sources[7,8,10,28]

version: 425, 2024/08/02

Glossary

Actuator	Device that performs an action, e.g. switch that turns on and off a pump or a device that opens or closes a window.
IO pins	IO stands for In Out, the pins on a Microcontroller board can be used electronically. receive signals and give them as output.
Node	A node is a point in a network that can received and forward information.
Sensor	Records a value, e.g. temperature, soil moisture.

Contents

Introduction

This document gives an overview of points of attention and sources and products that I have come across in the field of measuring and controlling in the garden with the help of sensors.

Working in the garden as a volunteer at Community Supported Agriculture (CSA) garden, I sometimes see opportunities to use sensors to get a better picture of the conditions in the garden and perhaps to automate certain tasks with the help of sensors, or to be able to control them from a distance.

On a hobby level, I am involved in making smart applications in the home. For example, I made a smart thermostat[1] that can control the temperature per room in the house and turns off in case no one is present.

A lot of development is occurring in recent years when it comes to automation in homes and buildings with 'smart' products. Think of climate control, lighting, security.

There is the rise of the Internet of Things (IoT), in which more and more devices have the function of being read and operated remotely, via an internet connection. Automation within buildings is not new, but it has now become more accessible. The techniques have become more common and products are produced on a large scale, resulting in lower costs and a wide range of products. Many techniques and software used in building automation and industry can be applied for use in the vegetable garden.

Image 1: Dashboard of a horticulturist with the software Home Assistant (source LED Gardener)

Applying automation can be useful to take some work off your hands and can contribute to achieving good conditions for the plants to grow, which can benefit the quality of the harvest.

Think of:

Sensors:

- Temperature sensors in the greenhouse spaces
- Soil Moisture Sensors
- weather station
- Cameras
- and more

Operation (actuators):

- Opening doors / windows greenhouses
- Watering
- and more

My knowledge of growing vegetables is not very large. Therefore, it may be that in this document applications are discussed that in practice are not at all a wish of the gardeners, are not necessary or are not practical. I just want to list the possibilities and offer ideas. Whether the gardeners want to do something with it is up to themselves.

Nor do I want to give the impression that this document is complete. It is a result of my own knowledge in the field of automation and an orientation on information published on the internet.

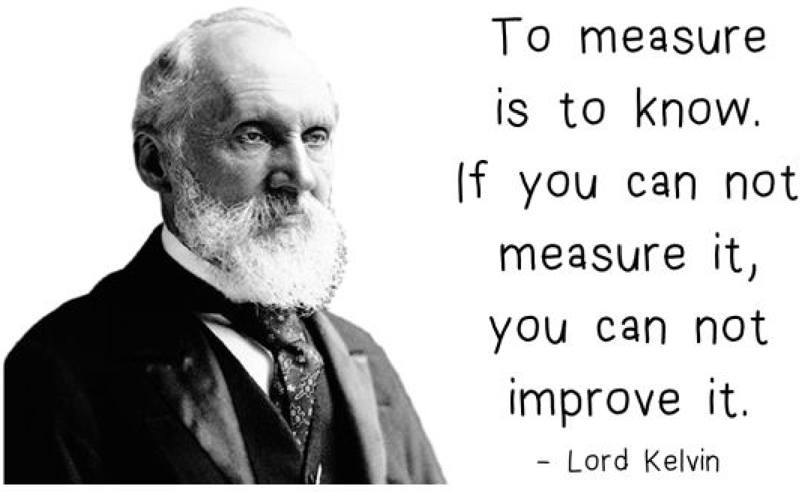


Image 2: A quote by scientist Lord Kelvin (1824 – 1907), famous British scientist.

1 The influences on the growth of a plant

When growing a plant, there are various influences that can have a positive or negative effect on the growth of a plant and its fruits.

A gardener wants to obtain a good harvest and achieves this through the attention and care of the plants. Much of this care revolves around controlling the conditions in which the plants grow. Many of these conditions are so-called *physical influences*.

These physical influences can often be measured with sensors, and the measurements are interesting to use as a reference in applying actions to reach optimized conditions, possibly in an automated way.

The following is an *incomplete* list of physical influences on plants:

- Sunlight
- Presence of water, soil moisture
- Temperature
- CO_2 content in the air
- Airflow
- Humidity
- Luminosity
- Leaf temperature
- Quality of soil
- Toxic substances in soil, air and groundwater
- Temperature of the spray water
- Composition of soil, minerals and pH value
- Weather conditions such as frost, hail and storm
- Harmful and beneficial insects and fungi
- microorganisms in the soil

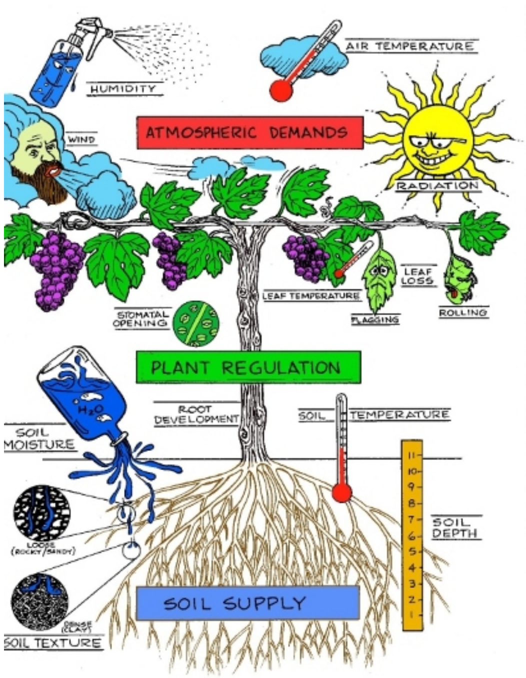


Image 3: Illustration[2] with influences on a plant

As a gardener, much of the work consists of dealing with these physical influences and controlling them as far as possible for the benefit of the optimal growth of the plants.

By means of automation with sensors and switches, it is possible to monitor and control many of these physical influences and thus allow part of the work to take place automatically.

2 Levels of automation that can be distinguished

When it comes to the application of sensors and automatic control in the garden, different levels of ‘deepness’ can be distinguished. In a design of a system, it is important to know to what level of automation is desired. A deeper level is more advanced. A more advanced system can have advantages, but also disadvantages. Therefore it is an important topic to discuss.

In the following sections, discussions of different levels follow.

2.1 Only monitor or also control?

A distinction can be made between the levels 'monitoring' and 'controlling'. Reading values and showing them on a display or an app on the phone is the level of monitoring. This also includes data logging, where a sensor value can be displayed in a graph over time. If the system design remains at the level of monitoring and action is required based on a sensor value, this can be carried out by a grower by hand.

Next to the ‘monitoring’ level a design with a deeper level, namely level 'control', can also be considered. This is a level in which the controlling actions are also automated based on the sensor values. Think of the automatic rolling up of the plastic of the tunnel greenhouses when the temperature has reached a certain height, so that ventilation will take place.

Just monitoring certain values can already be a win for the grower. Implementing the 'level monitoring' is easier than the 'level controlling'. The latter requires investing more time and money. When automating, it will always be necessary to carefully consider what it yields and whether it is worth the investment. It will also have to be taken into account that automation does not mean 'it looks after itself and monitoring won’t be needed'. It’s still important to oversee the site and be critical as a gardener to what is taking place. Extra checks and balances can be build in which a grower is warned if conditions are reached that need manual intervening, or that an emergency measure can be carried out automatically, so that there is no harmful situation for the plants.

2.2 Using the internet or a standalone circuit?

Another distinction between levels can be made between how an automation is technically designed. An automation can take place in an application with a central server where a dashboard can be monitored via the internet and can be operated via a website or app. These options are discussed in paragraph 6.3.
On the other hand, automations can also take place standalone, without external monitoring. In this case an electrical circuit is used. Often, a standalone application is a little simpler in nature and

faster to deploy. On the other hand, remote control can offer many additional options that are pleasant to use and offer advantages.

Here's an example. At Vegetable Garden de Haar, currently, irrigation is occasionally applied with timer plugs on the pump. You could call this a standalone automation with a circuit. Someone places the sprinkler heads and sets on the timer when and for how long to spray and then the spraying is automatically carried out at desired time and duration. This is quick to implement and is likely to go well all the time (although failing is possible).
It is also possible to automate this with a system where you can set from an app on the phone that watering should take place, with a switch on the pump that can be controlled from an app. For example, a system with opening and closing of water hoses with operable valves is possible. So that within a dashboard it can also be determined which compartments in the garden need to be watered. Can also be combined with extendable sprinkler heads. This second configuration is more advanced, so it's one level deeper.

3 Electricity and internet in the garden

3.1 Electricity

When monitoring or automating in the garden, there will be sensors that transmit signals and actions performed by actuators, such as a switch that controls a pump or a linear actuator that opens and closes a window. These requires electricity.

This electricity can be supplied in various ways. The electricity can be supplied by installing electric power cables in the garden (from the grid) or with the combination of solar panel and battery. Mainly for sensors, the use of batteries can also be an option. There are wireless sensors that are battery driven and can last a long time on a battery, depending on the wireless technique used. LoRa sensors are designed for low power use, more about this in chapter 7.

For actuators, devices that perform actions, more electrical power will be needed. For example, a pump or a motor that rolls up the tarpaulin of the greenhouses. In such applications, the question is whether the installation of a power cables is desirable, or whether a solar panel/battery can suffice.

Both options and their advantages and disadvantages are discussed below.

3.1.1 Power connection via underground cables

The installation of electricity via underground cables is probably the most ideal choice. The effort of this construction is then a one-time occurrence and can then be used for years. However, safety is a point of attention here. The garden is a place where there is regular change and the soil is milled. Under no circumstances should power cables be exposed and pose a hazard.

The videos below give an impression of the work required to install electricity in the garden. Possibly a permit is needed.

Link: How to feed cable through pipe or conduit in the garden

Link: Adding Electricity To A Permanent Greenhouse[3]

3.1.2 Combination solar panel battery

The installation of power cables come with a cost and the necessary work and time. An alternative that can be realized more quickly is a combination of solar panel and battery.

Think of configuration as in Image 4. This image is taken from a video by youtuber GreatScott[4], link: https://youtu.be/2YJHcGQnpAk?t=277

Image 4: Solar panel, battery and inverter as used in the youtube video of GreatScott

This youtuber uses a setup in which the battery is in a box with protection against rainwater:

It is estimated that the costs for the parts of the solar panel, inverter and battery are about €200.

Disadvantages of solar panel and battery
The disadvantage of using a solar panel and battery is that the reliability is not as high as with power from the grid. Batteries have a certain lifespan and after that they will have to be replaced, when the battery is at the end of life, there will be sudden failure, which can come unexpected and unnoticed. There is also the question of whether the battery performs sufficiently at lower temperatures. And whether the battery can be sufficiently charged at a time of the year with less solar power. Also, a battery has a more limited capacity than what power from a wall outlet can provide. For devices with higher power consumption, such as pumps, it will therefore be necessary to look carefully at whether a battery is sufficient.

Image 5: Image from youtube video Great Scott, box with a battery

3.1.3 Exceptions, applications without electricity

Sometimes there are applications that work without electricity. It can be an advantage to opt for this instead of an application that requires electricity because it is simpler.

Think, for example, of automatic openers of greenhouse windows, which work with cylinders. The heat in the greenhouse heats up a liquid in a cylinder. Expansion takes place and a mechanism is set in motion so that the window is opened at about 24 degrees. The windows close at 15 degrees when the cylinder cools down and shrinkage occurs. See images 6 and 7. However, it should be mentioned that it only controls the temperature, and not the humidity. To achieve optimal humidity, other applications are better, humidity is discussed in paragraph 12.2 Achieving the optimal humidity in the greenhouse.

Image 6: Automatic greenhouse room opener with cylinder

Image 7: Grille with automatic opening by means of cylinder

3.2 Internet connection

Depending on the form of automation chosen, it may be necessary to have a connection to the internet. Is there a desire to be able to read remotely from home or wherever? Then an internet connection will be required.

An internet connection via cable or ADSL is quite pricey and the subscription costs (in The Netherlands) will be around €40-60 per month. An alternative is to use a mobile subscription in combination with a router in which a SIM card can be inserted. To cut some costs, a second-hand router on from an Ebay type of marketplace would suffice. And it may well be that a relatively cheap mobile internet subscription with a few GB of data bundle will suffice, if it is only used for external communication via the Internet for the automation software, which doesn't have to take up a lot of data.

Image 8: An example of a Wi-Fi router where you can insert a SIM card so that mobile internet can be used for a system with remote access.

4 Conditions in the garden important to consider when choosing products

The garden is a different kind of environment than where automation is usually applied. In home and industry, often, automation will be applied within a building or house. In outdoor environments, the conditions are different. There are more temperature fluctuations, namely from temperatures below zero to above 30 ºC in summer, ofcourse depending on geographical location. Furthermore, there may be more exposure to water due to rain or condensed water. There will also be a strong wind every now and then. Furthermore, work is done in the garden and some rougher activities take place making it more desirable that equipment is sturdy and can’t be easily damaged.

It is therefore important to include this in the design of measurement and control technology. As a result, many products for the consumer market and for buildings will be less suitable. The materials should preferably be chosen as robust as possible. It will also have to be taken into account that used products will can be expected to have a shorter lifespan than if they were used indoors.

5 Difference between wired and wireless communication

Within a system of sensors and actuators, communication takes place. Sensor data needs to be read and actuators started and stopped. This can be done via a wired or via wireless communcation. Both options have their advantages and disadvantages.

Image 10 Ethernetcable

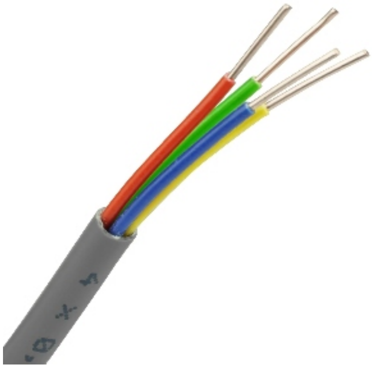


Image 9: signal cable, multicore

Wired connection can be ethernet cables, for example, see Image 10. Or other signal cables, such as multicore copper signal cables (Image 9).

In general, wired communication is more reliable than wireless communication. In industrial situations such as factories, wired systems are more likely to be used than wireless ones, because of that higher reliability. Wired communication can also handle longer distances than most wireless protocols, for example, WiFi signal has a range of about 100 m (in ideal conditions) and also gets weaker with growing distance.

However, there are wireless protocols that are suitable for longer distances. An example of this is LoRa (Long Range). LoRa is a protocol developed for long distances, kilometers. In addition it has low energy consumption. This makes the technique suitable for use with batteries on which they can run very long, which is convenient. More about LoRa in Chapter 7 .

It will depend on the situation and the application which choice to make. The achievable distance plays a role, but so does the cost, the amount of time and work for installation and also the desired reliability. As for that reliability, here’s an example: for a weather station, it won't be so bad if a temperature or humidity reading doesn't come through a few times a day to still get a good picture. But, if a gardener wants to control soil moisture and do automatic irrigation, it is much more important that communication runs flawlessly.

Table 1 provides an overview of the advantages and disadvantages of the two types of communication.

Table 1: Overview Advantages and Disadvantages of Wired and Wireless Communication

	Wired	Wireless
Advantages	• Long-distance communication possible • Reliability higher than wireless	• Cheaper than wired • Many ready-to-use applications on the market • LoRa protocol can be used, can be used in combination with batteries • Mesh network sometimes possible, where the nodes also pass on information, makes a network more stable.
Disadvantages	• More material costs • Laying wiring is more time-consuming	• Distance is limited for commonly used protocols (Wi-Fi, Zigbee, Bluetooth) • Reliability less than wired • Some people feel that radiation can interfere with nature • A frequency band can be filled up by other users nearby or many devices

Power over Ethernet

With wired communication, depending on the technology used, both communication and power supply can be offered at the same time. An example of this is Power over Ethernet (PoE). This is used with security cameras, for example. Only one cable goes to the camera. This can be done over a longer distance of hundreds of meters. That means you don't have to pull an extra power cable to the camera. Sensors and microcontroller boards sometimes also have PoE available.

Image 11: Power over Ethernet application with a camera

5.1 Electromagnetic radiation from wireless networks, bad for plants and animals?

It is very common nowadays to use wireless techniques. Almost every house in the Netherlands has a WiFi network, to which computers, laptops and telephones are connected. Many consider this to be safe and without affecting humans, but there are also voices from researchers who think otherwise.

Given that vegetable garden de Haar considers it of paramount importance not to burden the environment, it is good to pay attention to 'radiation pollution' in this report.

During the orientation, a scientific publication[5] was viewed, which spoke of a negative influence of WiFi on plants. A remark on this research may be that the distance from the WiFi router to the plants is chosen very close (8 – 30 cm). In practice of the garden, the distance will usually be greater, although the radiation can increase with more Wi-Fi devices.

The image below is from that publication:

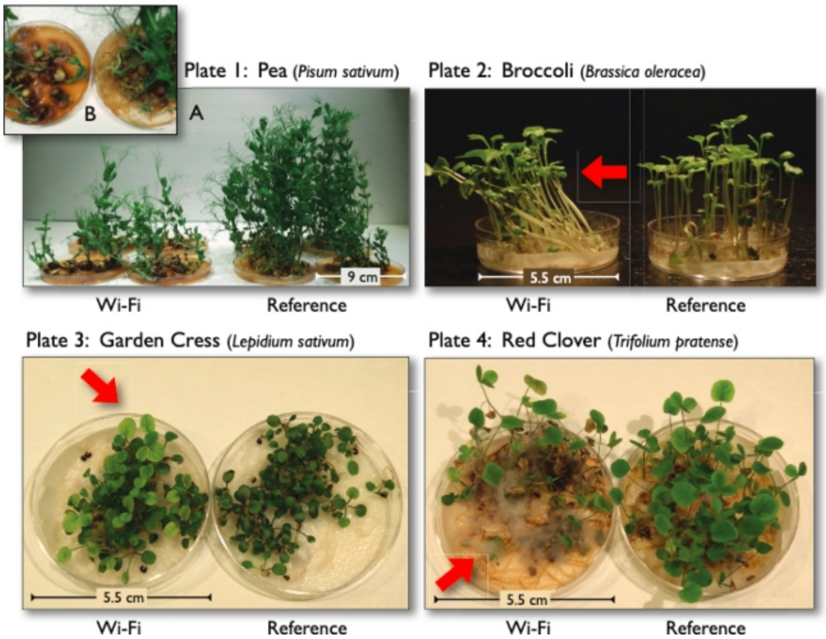


Image 12: Images taken from scientific publication, see Appendix A. In some plants, there seems to be a clear influence of Wi-Fi.

Concerns about the effects of radiation on humans, plants and animals can be a reason not to choose WiFi as a technology. In Chapter 7 LoRa is discussed separately. This is also a wireless technique, but has a lower impact, because the signal strength is less high and information is transmitted at intervals.

RF (433Mhz or 868Mhz) products can also be suitable for radiation avoidance. These communicate with short packets of data. Click-on plugs are an example of RF technology.

To avoid wireless altogether, the choice can also be made for wired communication.

6 Automation with remote control requires a server

When designing a system where a gardener can monitor and configure the system via web browser or app, this will be is a system that works with a central server. A server is a central computer that communicates with the sensors, switches, and actuators in the garden. The 'thinking' takes place on the server. The server ‘determines’ whether actions need to be performed based on the values of the sensors and the set configuration in the software.

Roughly speaking, a system with a server, regardless of which manufacturer makes the products looks something like Image 13.

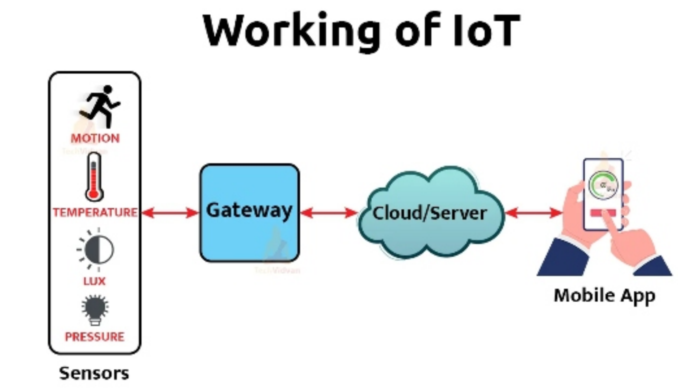


Image 13: Schematic map of a configuration with a server. The images on the left depict sensors and controllers. A gateway is a device that is sometimes needed to pass the data to and from the server. Image origin: Internet.

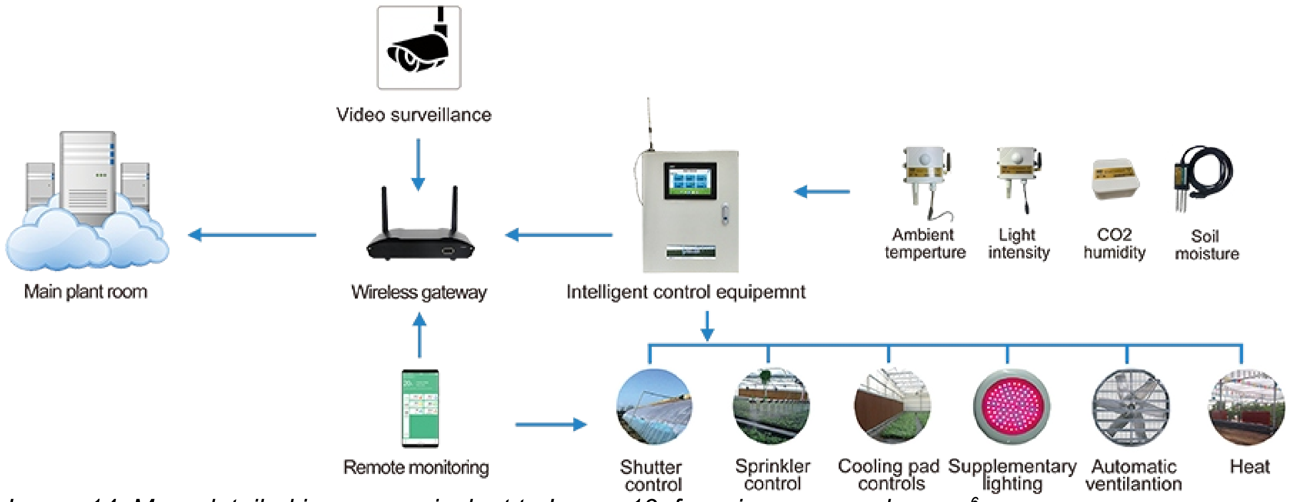


Image 14: More detailed image, equivalent to Image 13, focusing on greenhouses[6].

During the orientation on the possibilities of automation in a garden, several providers of systems with a server were found that focus specifically on agriculture.

Such systems all have a *user interface*, also known as a *dashboard*, to which can be logged in via a web browser on the computer and/or an app on the phone.
Through that interface, the user can do the following actions:

- **Viewing the values of the sensors (monitoring)**
- **Configuring the system**
- **Set which actions to be done based on triggers and conditions (automations)**
  A trigger can be: "The temperature in the greenhouse is higher than 30° C."
  A condition can be: "It's not raining"
  An action can be: "Start the roller motor for rolling up the tunnel greenhouse"

Such an interface looks different for each provider. Two examples of dashboards of software packages can be seen in Image 15 (Orisha) and Image 16 (Home Assistant). Both systems are discussed in section 6.3 .

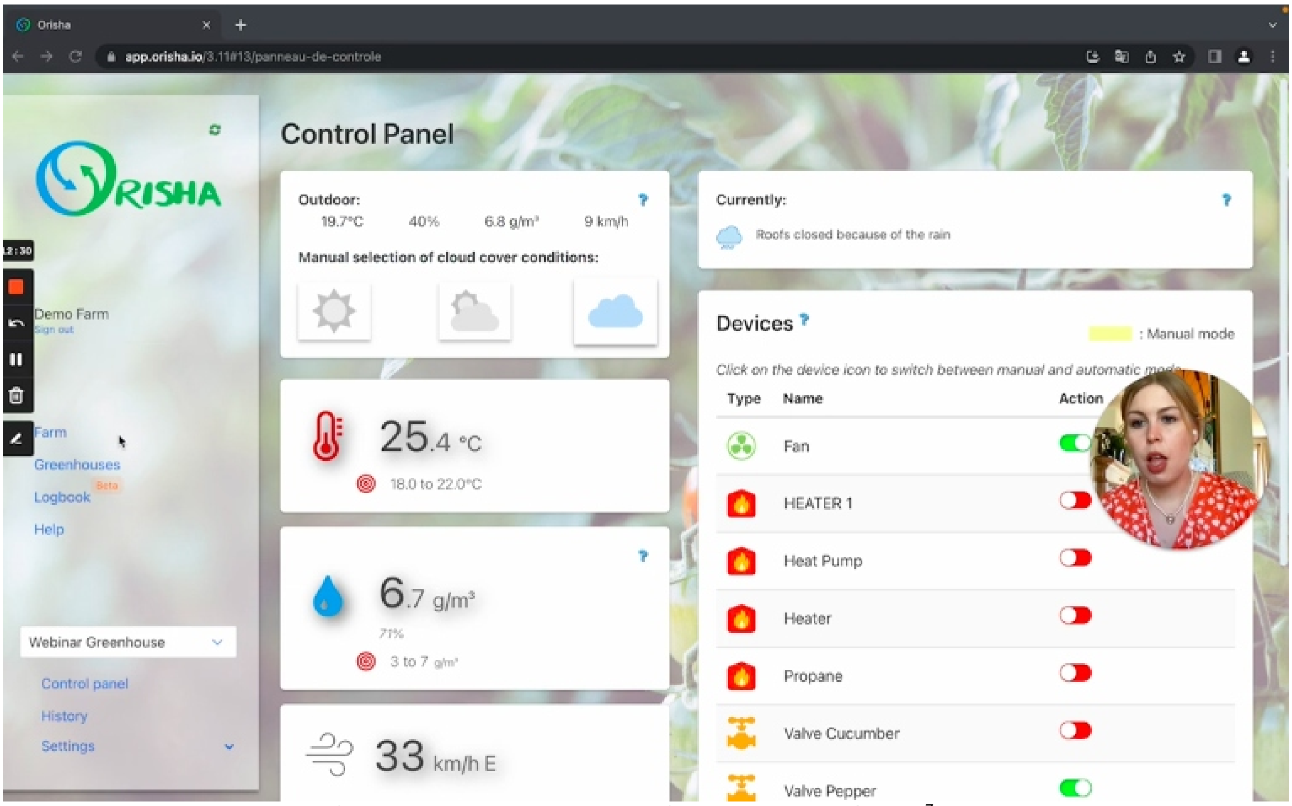


Image 15: The dashboard of greenhouse automation software provider Orisha[7]

Image 16: Dashboard using software package Home Assistant, as applied by the youtuber LED Gardener[8]. Opened here on a tablet.

Roughly speaking, such software systems are all similar in terms of capability of showing sensor values and showing switches and options for automations. But there will be many differences in the following areas:

- **Degree of user-friendliness**
- **Configuration options**
- **Complexity of the automations to be set up**
- **Protocols support**
  There are several protocols: WiFi, LoRaWAN, MQTT, RS485 Modbus, etcetera, and it depends on the server software whether they are supported. The supported protocols determine which products (sensors and actuators) this system can work with. Some providers will offer or referenced a line of products that work in conjunction with the software.
- **Degree of support from the supplier**
  An important criterion to take into account is what help a supplier can offer. Are they easy to reach for questions? Do they have good documentation available for setup and troubleshooting?

6.1 Open source vs. commercial

An important consideration when choosing the software for automation is whether the software is made by a commercial provider or whether it is 'open source'.

Open source
Open source means that the creators of the software work together over the internet, where anyone can suggest improvements that can be accepted by the team behind the software and included in the most recent released version.

The code of open source software is freely available on the Internet and free of charge and can be copied and used by anyone. The advantage of this open source model is that a large group of programmers, hobbyists but also companies, can work together on creating the software. If there is a lot of enthusiasm around a software program, that group can grow and a strong product can be created. A product that, if it had to be made by a company, would have had large development costs and therefore a high price for the customer.

Image 17: Logo Wordpress, a well-known and successful Open source project

A well-known example of open source software is Wordpress, a widely used content management system for creating websites. Wordpress is also used by Vegetable Garden de Haar. Another example is Android, the operating system for phones which is based on Linux. This is also open source and a large portion of phones in the world run on this.

Commercial software

In the case of software created by a company, the software code is not public and the company owns it. With this model, the customer pays a one-time or periodic fee to be able to use the software.

Table 2 Shows an overview of advantages and disadvantages of open source software and commercial software.

Table 2: Overview Pros and Cons of Open Source and Commercial Software

	Open source	Commercial
Advantages	Low cost, because the software can be downloaded free of charge. If it's a project with a lot of contributors and users, it's developing quickly, there's a lot of maintenance on the software code.	Company often offers opportunities to contact in case of problems and questions. The company has an interest in keeping you a customer and that is an incentive to quickly fix any errors in the software.
Disadvantages	There is no organization behind it that is a point of contact for questions and problems. However, the software may have good documentation. Furthermore, the user has to rely on resources on the internet and forums to ask questions	The costs are higher due to purchase and/or subscription costs The continuity of a software company is not guaranteed. A company can stop using a product or go bankrupt. This can create a problem for the users. An open

	or external companies.	source project can also fail, but for a popular open source project this is not to be expected.

6.2 Cloud-based or fully on-premise

An important aspect to consider when choosing a server-based system is whether it uses a so-called cloud or whether it functions in a local network.

The 'Cloud' is a term used for software that runs on the supplier's computer. Many products in the field of smart sensors and automation work together with the supplier's cloud.

Image 18: The term 'Cloud' conjures up a somewhat strange image, but it's just a computer that's in a server park somewhere, to which a device is communicating with

The cloud model has advantages and disadvantages, the advantages are:

- There is no need for a server on the premises, which reduces the acquisition cost for the user
- Configuring the products typically requires fewer technical actions
- The technical maintenance of the server part is in the hands of the supplier

The disadvantages of the cloud model are:

- An internet connection is required for communication with the sensors and actuators. In the event of an internet outage, functionality is lost.
- There is a dependency on the supplier. If the supplier stops the product or the supplier goes bankrupt, it is uncertain whether the functionality will remain intact
- There is no one-time purchase, but often the user also pays for a subscription for the use of the cloud services
- Typically, only the company's own brand sensors and actuators work. There may be a so-called vendor lock-in.

On – premise
An alternative to the cloud model is a configuration with a server that is installed locally. Although this is slightly more expensive to buy, it does provide more certainty in the long run that products will continue to work regardless of whether the manufacturer continues to offer them or not.

The advantages of a local configuration are:

- The system will continue to work if the internet connection is lost
- There is no dependency on a company, which can terminate its products and services

The disadvantages are:

- Slightly higher purchase costs, because a server is run locally
- The management of the server will have to be done yourself, although these can be very user-friendly

6.2.1 Vendor Lock-in

As mentioned in the disadvantages of a system with a cloud dependency, it can happen that a manufacturer can only work with products of its own brand or a number of certain brands. This is referred to as a vendor lock-in. The user then has only a limited choice of sensors and actuators that can communicate with the system. Usually this is not the most advantageous option financially and not all available products will meet the requirements for the situation in the garden. So this can be seen as a disadvantage.

6.3 Providers of garden and greenhouse automation

In the following paragraphs, suppliers of automation systems for agriculture that were found in the garden during the orientation on the topic of automation are discussed. This is not an exhaustive list. It's just the companies that were observed during the orientation.

6.3.1 Orisha

Name:	Orisha
Website:	https://www.orisha.io
Open source of commercieel:	Commercial
On-premise or cloud:	Cloud-based
Located in:	Canada

Orisha is a company that publishes automation software and hardware, which focuses on smaller gardeners, 'market gardeners'.

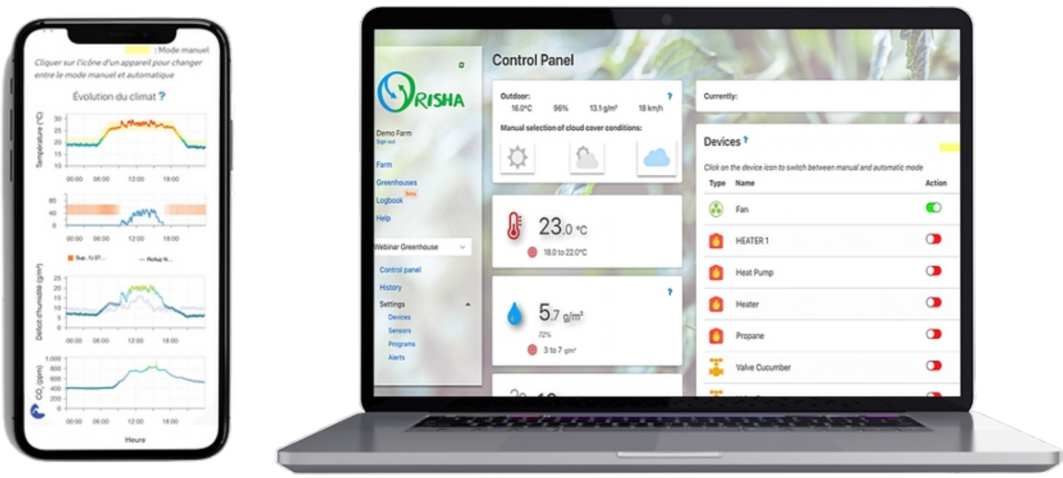


Image 19: Reading and control via app and browser with the Orisha system

The cost of Orisha starts at $35 / month. Orisha also has income from selling parts such as sensors and actuators.

There are several testimonial videos of Orisha users on Youtube and on the site of Orisha. It is good to mention that the impression is that these users have received a quid pro quo, such as a discount, because the videos are mostly published on the youtube channel of Orisha itself, and because the videos do not seem to be completely independent in their judgment.

The following video is an interesting video in which a horticulturist talks about his experiences with the Orisha system.

Link: [The Secret To PERFECT Greenhouse Crops | Greenhouse Automation]

Furthermore, many videos made by Orisha can be found on the youtube channel of Orisha itself.

Impression:

The Orisha company is a young company and has a relatively small team of employees. Presumably, therefore, the cost of the product is relatively not very high and is affordable. Because their team is so small, it is though expected that the user may run into limitations within the possibilities of Orisha's software. It is not likely that the software is very advanced, with the small team of software developers. In practice, it may well be the case that there are wishes of the user that are not adjustable.

The product also comes with a cloud dependency which can be considered as a disadvantage to choosing their product. Given that it is such a young company, it is unclear whether they will survive and survive in the long term, and their cloud software could then become unusable, making it necessary to switch vendor.

An advantage of Orisha is that they can be approached for questions and offer information about which products their system works with. That can be useful, 'reinventing the wheel' is then less necessary.

6.3.2 Home Assistant

Name:	Home Assistant
Website:	https://www.home-assistant.io/
Open source of commercieel:	Open source
On-premise or cloud:	Local
Located in:	Not applicable, open source
Cost:	Available for free

Home Assistant is a software program that works as a central server for communication with sensors and actuators. In addition, it also offers a so-called 'front-end' or ‘dashboard’ where the user can read the values and configure the system. Although the name Home Assistant suggests that it is software that is made for applications in homes and this is where it initially is designed for, Home Assistant is also very suitable for applications other than homes. Many of the communication protocols that can be applied in homes can also be used more widely in, for example, factories, but also gardens.

Home Assistant is open source software and is available free to download. It is currently very popular among engineering hobbyists and has millions of users worldwide and many programmers who contribute to its development. Home Assistant has a vibrant community. As a result of this the development of the software goes very fast and problems are reported and picked up quickly. Also, there are many enthusiasts who publish tutorials on YouTube or elsewhere on the internet.

Home Assistant can work with the vast majority of devices on the market. Therefore it makes it possible to make products that are from different brands and communication protocols work together.

Home Assistant is installed on a computer that serves as a server. This can be, for example, an old laptop or a Raspberry Pi microcomputer with SSD drive.

Some images found on the internet of dashboards with Home Assistant applied to greenhouses are below.

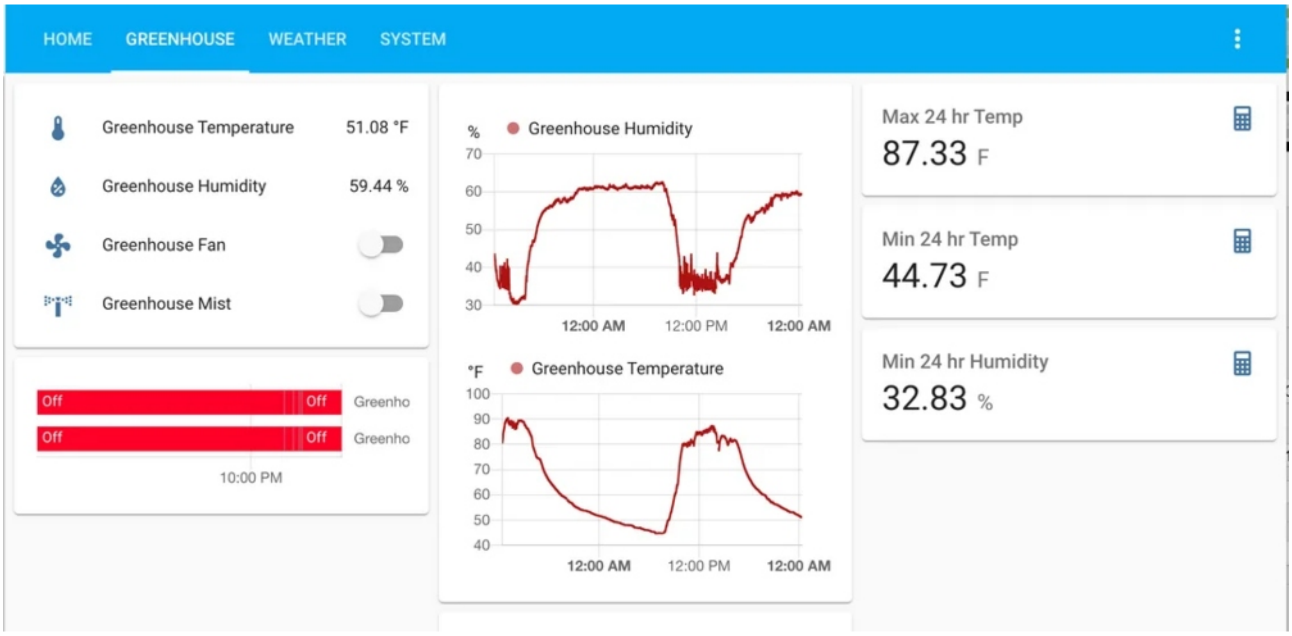


Image 20: An example of a Home Assistant-enabled dashboard, as displayed in a browser or tablet. Shared by a user on the web[9]

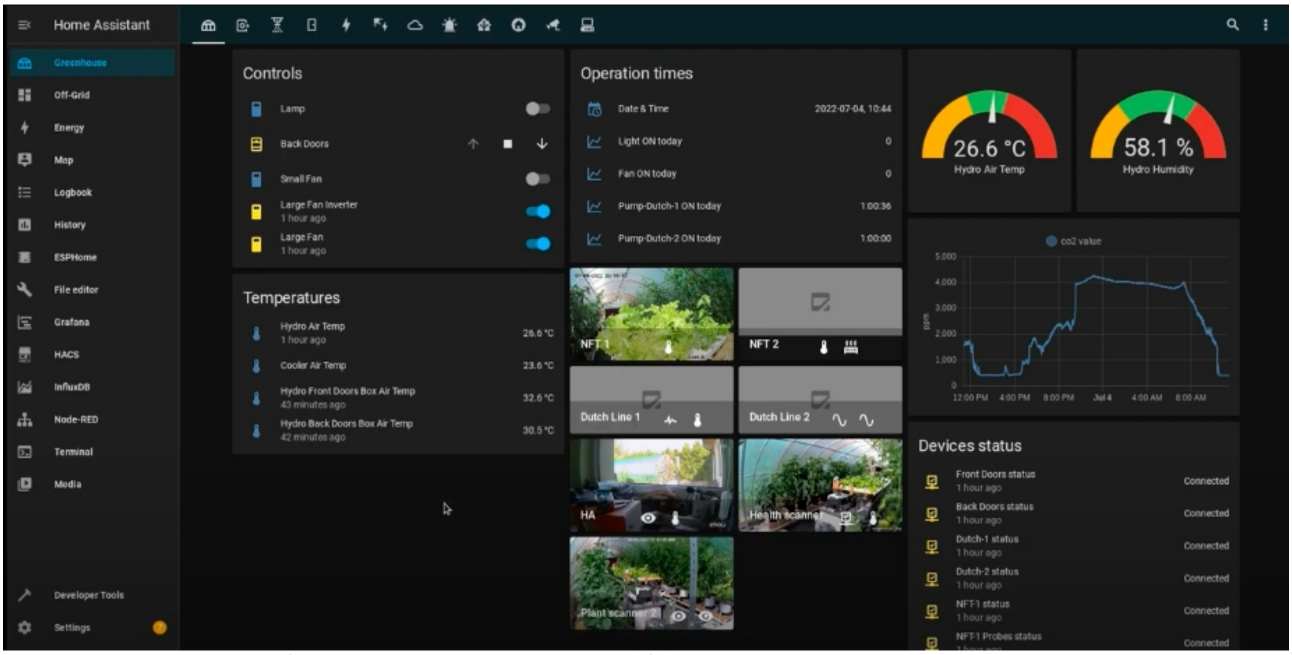


Image 21: Dashboard of a user using Home Assistant for a greenhouse with hydroponics growing method. This user uses cameras and also has a CO_2 meter, the course of which is shown in a graph. Image taken from a youtube video[10].

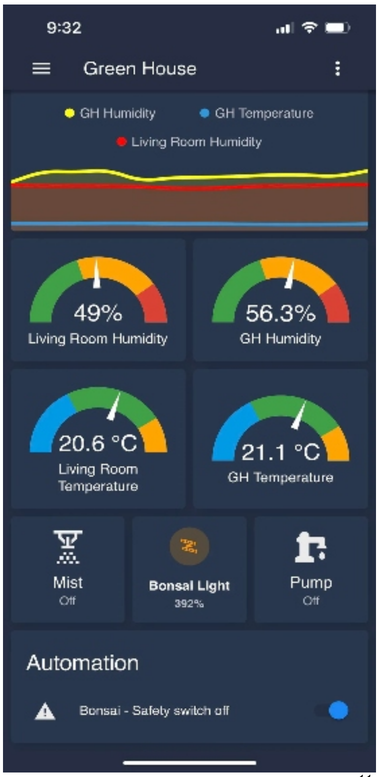


Image 22: User-shared image[11] of a dashboard as displayed on the mobile phone

An interesting video in which the possibilities of Home Assistant in combination with growing vegetables is discussed is the one below from LED Gardener. However, it is important to note that the creator of these videos makes all kinds of modules himself instead of buying ready-made modules. Since he has the skills to make these modules himself, he will be able to solve defects quite fast. For most growers it is probably wiser to opt for a configuration with ready-made modules, this is discussed further in Chapter 10 Self-assembly modules versus ready-to-use products. However, the video does give a good image of what is possible with Home Assistant. The LED Gardeners configuration can also be achieved with 'plug & play' products.

Link: Update on My Automated Garden System (Plus System Diagram, Parts List, & All Code Now Shared!)[12]

Impression:

The Home Assistant system seems to be very suitable for use in the garden. It has a low cost and can be adapted very well to the wishes of the user. The advantage is that it is not cloud-dependent, which makes it a future-proof solution, no company that can pull the plug and discontinue. It cooperates with many products in the market. Almost any product with some form of communication can be included in the system.
Since it is open source, there is no support from any company. However, there are a lot of resources available on the internet and Home Assistant is becoming so common that it may also be possible to hire technicians for it, if necessary.

6.3.3 Other providers

During the orientation, the following companies were also found that offer software for monitoring and control. In order to keep this report somewhat compact, they are only briefly mentioned below.

Name:	30Mhz
Website:	Hatpas://30mahj.com/nl/
Open source of commercieel:	Commercial
On-premise or cloud:	Not yet determined
Located in:	Rotterdam, The Netherlands

Name:	Link4Controls
Website:	Hatpas://link4control.com/
Open source of commercieel:	Commercial
On-premise or cloud:	Cloud-based
Located in:	United States
Cost	High

7 LoRa sensors, long-distance wireless communication

This document has references to all types of sensors and communication protocols. In this chapter, sensors with the LoRa communication protocol are highlighted, because they seem to be very suitable for use in the vegetable garden.

LoRa is an abbreviation for Long Range and is a wireless communication protocol, which is therefore suitable for communication over longer distances. It is also designed for low energy consumption, which is why sensors can run on batteries for years.

To get LoRa working in the garden, a LoRa gateway is needed:

Image 23: A LoRa gateway from the brand Dragino[13]

The gateway is the receiver of the measured values of the LoRa sensors below. The Gateway can then pass them on to a server such as Home Assistant (Paragraph 6.3.2).

During the orientation, the products of manufacturer Dragino stood out as a line of LoRa products suitable for agriculture. See screenshots below (images 24 and 25) of Dragino's website.

Model	Photo	Description
WSC2-LB -- Main Process Unit		LoRaWAN main process unit in Dragino Weather Station solution Outdoor LoRaWAN RS485 end node Powered by external 12v solar power. Built-in li-on backup battery Support Bluetooth v5.1 and LoRaWAN remote configure Support wireless OTA update firmware
LMS01-LB -- LoRaWAN Leaf Moisture Sensor		LoRaWAN Leaf Moisture Sensor LoRaWAN 1.0.3 Class A Bands:EU433,CN470,EU868,IN865,KR920,AS923,AU915,US915 Ultra Low Power Consumption Monitor Leaf moisture Monitor Leaf temperature Support Bluetooth v5.1 and LoRaWAN remote configure Support wireless OTA update firmware 8500mAh Battery for long term use
SPH01-LB -- LoRaWAN Soil pH Sensor		LoRaWAN Soil pH Sensor LoRaWAN 1.0.3 Class A Bands:EU433,CN470,EU868,IN865,KR920,AS923,AU915,US915 Ultra Low Power Consumption Monitor soil pH with temperature compensation. Monitor soil temperature Monitor Battery Level Support pH calibration by end user Support Bluetooth v5.1 and LoRaWAN remote configure Support wireless OTA update firmware 8500mAh Battery for long term use
SE01-LB -- LoRaWAN Soil Moisture & EC Sensor		LoRaWAN Soil Moisture & EC Sensor Bands:EU433, CN470,EU868,IN865,KR920,AS923,AU915,US915 Monitor Soil Moisture Monitor Soil Temperature Monitor Soil Conductivity Temperature Compensation Ultra Low Power Consumption Support Bluetooth v5.1 and LoRaWAN remote configure Support wireless OTA update firmware 8500mAh Battery for long term use
UV254-LB -- LoRaWAN UVC Radiation Sensor		LoRaWAN 1.0.3 Class A Bands: CN470/EU433/KR920/US915/EU868/AS923/AU915/IN865 Detect UVC lamp working status,working efficiency Peak response spectrum 254nm Support Bluetooth v5.1 and LoRaWAN remote configure Support wireless OTA update firmware
SDI-12-LB -- SDI-12 to LoRaWAN Converter		LoRaWAN 1.0.3 Class A Ultra-low power consumption Controllable 5v and 12v output to power external sensor SDI-12 Protocol to connect to SDI-12 Sensor Bands:CN470/EU433/KR920/US915/EU868/AS923/AU915/IN865 Support BLE and LoRaWAN remote configure Support wireless OTA update firmware
NLMS01 -- NB-IoT Leaf Moisture Sensor		NB-IoT Leaf Moisture Sensor NB-IoT Bands: B1/B3/B8/B5/B20/B28 @H-FDD Monitor Leaf moisture Monitor Leaf temperature Ultra Low Power Consumption Micro SIM card slot for NB-IoT SIM
NSPH01 -- NB-IoT Soil pH Sensor		NB-IoT Soil pH Sensor NB-IoT Bands: B1/B3/B8/B5/B20/B28 @H-FDD Monitor soil pH with temperature compensation. Monitor soil temperature Ultra Low Power Consumption Micro SIM card slot for NB-IoT SIM
GroPoint Air - LoRaWAN Multi Segment Soil Sensor Converter		Directly Supports GroPoint Profile Global LoRaWAN Bands. LoRaWAN v1.0.3 Class A Protocol IP66 Waterproof Enclosure 8500mAh Battery for long term use

Image 24: Dragino's products with LoRa technology with applications in agriculture, part 1

WSS-07 – PAR (Photosynthetically Available Radiation)		Measure 400 ~ 700nm wavelength nature light's Photosynthetically Available Radiation.
WSS-06 – Total Solar Radiation sensor		RS485 Total Solar Radiation sensor Measure Total Radiation between 0.3～3μm（300～3000nm)
WSS-05 – Temperature/Humidity /Illuminance/ Pressure		RS485 Temperature, Humidity, Illuminance, Pressure sensor
WSS-04 – Rain & Snow Detect		RS485 Rain/Snow detect sensor Surface heating to dry grid electrode uses Electroless Nickel/Immersion Gold design for resist corrosion
WSS-03 – CO2/PM2.5/PM10		RS485 CO2, PM2.5, PM10 sensor NDIR to measure CO2 with Internal Temperature Compensation Laser Beam Scattering to PM2.5 and PM10
WSS-02 – Wind speed and direction sensor		RS485 wind speed / direction sensor PC enclosure, resist corrosion
WSS-01 – Rain Gauge		RS485 Rain Gauge Small dimension, easy to install ABS enclosure.
WSC1-L – Main Process Unit		LoRaWAN main process unit in Dragino Weather Station solution Outdoor LoRaWAN RS485 end node Powered by external 12v solar power. Built-in li-on backup battery
LSPH01 – LoRaWAN Soil pH Sensor		LoRaWAN Soil pH Sensor LoRaWAN 1.0.3 Class A Monitor soil pH with temperature compensation. Monitor soil temperature Monitor Battery Level Support pH calibration by end user LoRaWAN EU433, CN470,EU868,IN865,KR920,AS923,AU915,US915 Ultra Low Power Consumption
LLMS01 – LoRaWAN Leaf Moisture Sensor		LoRaWAN Leaf Moisture Sensor LoRaWAN 1.0.3 Class A Monitor Leaf moisture Monitor Leaf temperature LoRaWAN EU433, CN470,EU868,IN865,KR920,AS923,AU915,US915 Ultra Low Power Consumption
NSE01 NB-IoT Soil Moisture & EC Sensor		NB-IoT Soil Moisture & EC Sensor NB-IoT Bands: B1/B3/B8/B5/B20/B28 @H-FDD Monitor Soil Moisture Monitor Soil Temperature Monitor Soil Conductivity Ultra-Low Power consumption Micro SIM card slot for NB-IoT SIM
LSE01 – LoRaWAN Soil Moisture & EC Sensor		LoRaWAN Soil Moisture & EC Sensor LoRaWAN EU433, CN470,EU868,IN865,KR920,AS923,AU915,US915 Monitor Soil Moisture Monitor Soil Temperature Monitor Soil Conductivity Temperature Compensation Ultra Low Power Consumption

Image 25: Dragino's products with LoRa technology with applications in agriculture, part 2

The different weather modules can be assembled into a weather station as shown below:

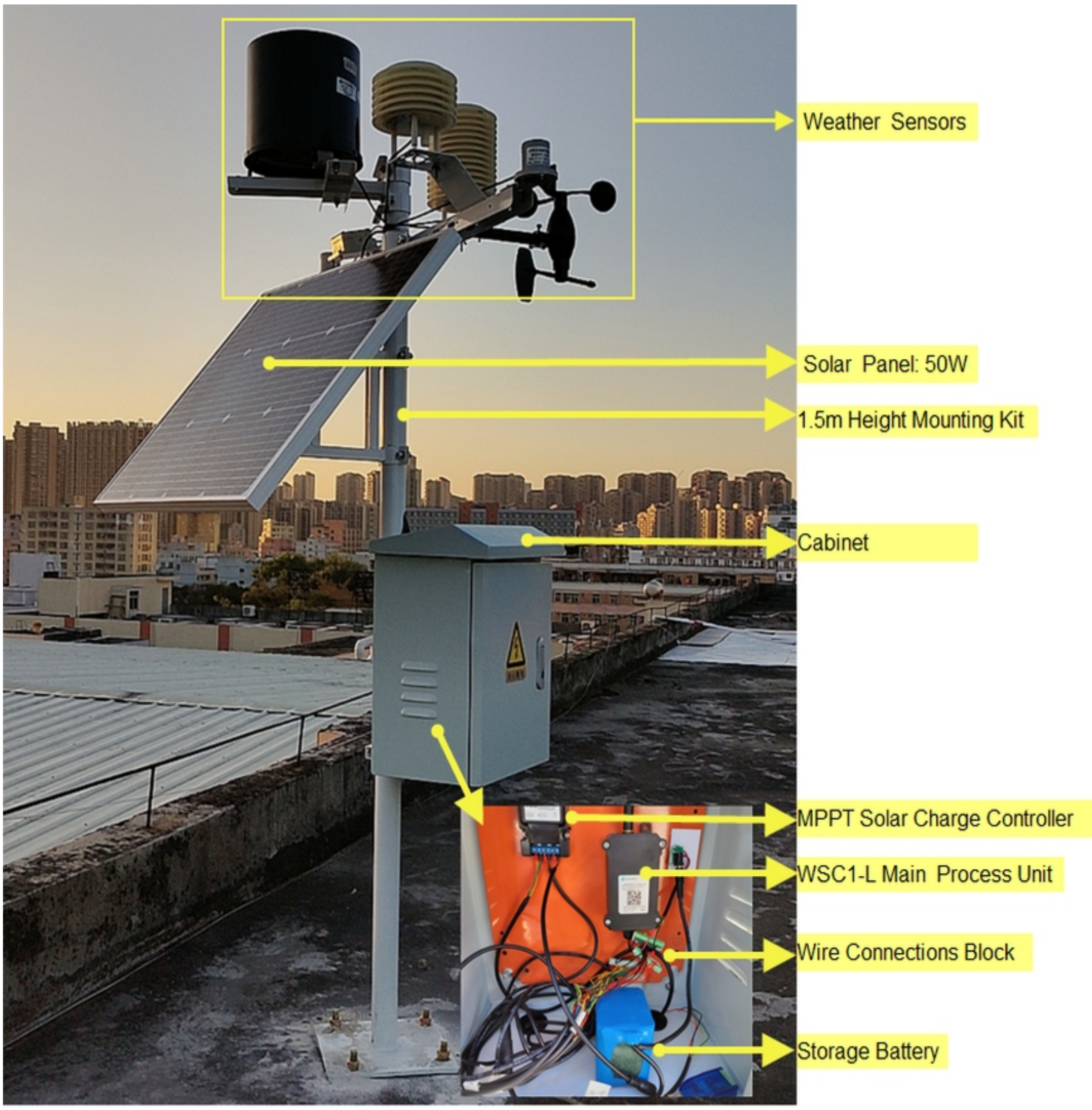


Image 26: Example of a configuration with the Dragino LoRa basic module for weather stations with various modules.

On the site of Seeedstudio you can also find LoRa products:
https://www.seeedstudio.com/LoRaWAN-Device-c-1920.html

8 AliExpress as a place to buy products, yes or no?

We live in a time when a lot of electronics are used and those products are often made in low-wage countries. China is a well-known 'manufacturing country' and nowadays even products can be ordered directly from China via online marketplaces such as AliExpress. AliExpress has a very wide range of products, including a wide range of sensors and actuators. The prices are low and even the shipping costs and delivery time are acceptable. For the hobbyist, it can be an advantage to find just that one sensor for that nice price to tinker with. At first glance, it also seems to be a place where it is beneficial for Vegetable Garden de Haar to order sensors and other parts for measuring and controlling in the garden.

Image 27: Logo AliExpress, site to be visited via https://www.aliexpress.com

At the same time, Vegetable Garden de Haar is a place that attaches great importance to sustainability in terms of nature, the environment and society. These concerns may not be consistent with ordering from sites like AliExpress. It is therefore questionable whether a marketplace such as AliExpress should be used when purchasing sensors and actuators.

Some negatives of buying from AliExpress may include:

- The products do not have to meet the same safety requirements as products within the EU. Low-voltage products do not have a high safety risk, purchasing high-voltage products (220 volts) is not recommended.
- It can be unfair competition with local companies in the country of the receiver
- Chinese companies sometimes violate patents, which is unfair competition against companies that invest time and money in developing a product.
- It is unclear whether the working conditions are on par what we consider desirable here
- For transport, they have to come all the way from China, even if this is bundled in large containers. That is more harmful to the environment.

On the other hand, some of these disadvantages also apply to products that are in local stores in the country of the reciever, because these are also often produced in low-wage countries. In today's society, it is unavoidable to buy products that come from those countries. And furthermore, it can sometimes be an advantage that the range of products on AliExpress is so large, so that you can buy just that one specialist product. And maybe from another perspective it is more fair if a consumer can buy directly from the maker.

So it will be a consideration whether to use sites such as AliExpress and something that perhaps should be looked at per type of product.

9 Does a sensor really give the right value? Calibration and control of the values

If, as a gardener, you want to focus on sensors that display certain values, it is important that the displayed value is actually reliable. In practice, consumers often buy a sensor and assume that the displayed value is correct at the time the sensor is put into use.

Depending on the application, a deviation in the measured value from the actual value can have consequences. So it's a good idea to check a sensor against a known value, as discussed in paragraph 9.1. It is also important that the grower keeps in mind when working with sensors that sensor values need to be critically assessed and that is a good practice to check the sensors against known values one or more times a season.

A sensor can deviate in two ways. A sensor may not display the correct values in a certain measurement area or may not be correct in the entire measurement area.

A bad functioning sensor often has to do with the quality of the sensor, which can vary. It is also possible that a sensor requires calibration. When looking for a sensor, it is smart to first buy one piece and test it against physical constants, see paragraph 9.1. Consulting the internet for other people's findings with a certain sensor is also a good idea.

Sometimes the specifications of a product state what the part number of the sensor that is used in the product. For example, temperature and humidity sensors like DHT22, the SHT31 or BME280 (also air pressure) are well known sensors in the lower price range. For example, the site Science in Hydroponics[14] reports that there are bad experiences with the DHT22 sensors, but good experiences with the SHT31 and the BME280.

9.1 Verification of sensors

In order to determine whether the displayed reading value of a sensor corresponds to the actual value, a measurement can be taken in a situation where it is known which reading value it should give.

Here's an example. A humidity sensor that measures in relative humidity displays the humidity in 0-100%. To control these, it is possible to use saturated saline solutions. It is known from physics that a sealed container with saturated solutions of a salt, at room temperature, has a known humidity in the space above the liquid. Different salts (e.g. Sodium chloride, potassium acetate, ammonium nitrate) produce different humidity values for the air in a sealed container, known for that substance. By placing the sensor in such a container (or zip bag), it can be checked whether the displayed humidity is equal to the humidity produced by the saline solution in question. The dissolved salts therefore provide reference values.

The different humidity values known for different salts are shown in the graph in Image 28. They are often independent of temperature.

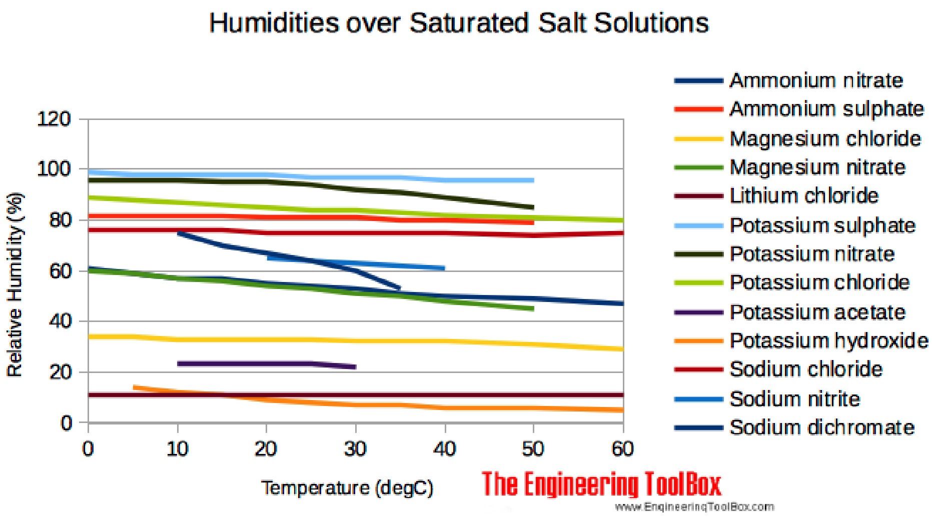
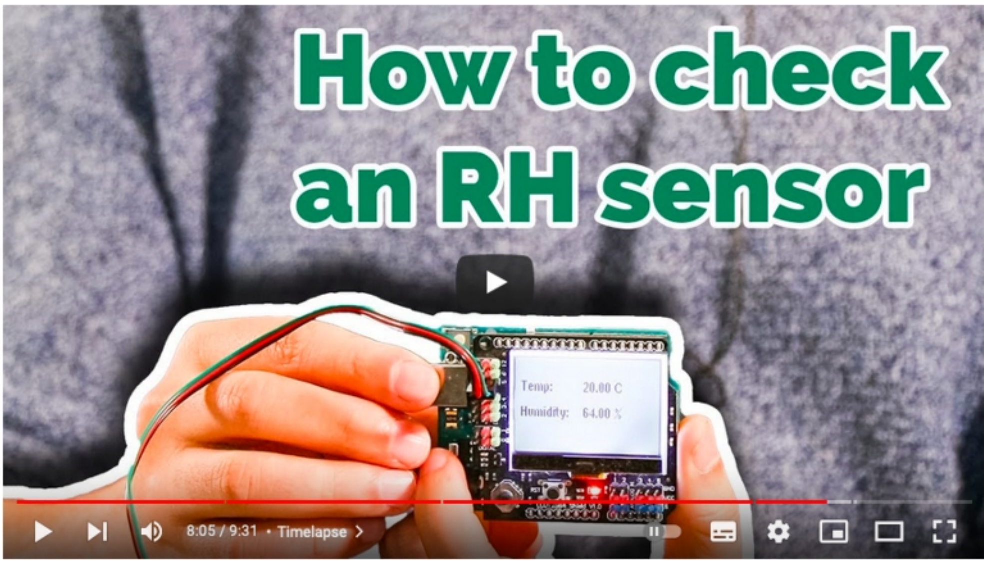


Image 28: Humidity values of air above saturated solutions of salts used in checking or calibrating humidity sensors. It can be seen that each salt offers a separate humidity in the space above the solution and that it often remains stable with changing temperature.

Image 29: Calibration kits that are available for sale ready-made. These from the Boveda brand are made to check the measuring point 75% and 32%.

In the video below from the Science in Hydroponics channel, an explanation is given on how to check whether a sensor is displaying the correct value using a saturated saline solution.



Link: [How to test relative humidity sensors]

Also on the site of Science in Hydroponics[15] there are several articles about calibrating and/or checking sensors, [Link].

There are also methods to check the measured values for other types of sensors, such as those for temperature, soil moisture, etc.

In addition to checking sensors from time to time, it is also smart from a reliability point of view to use multiple sensors instead of just one sensor. By comparing multiple values, a deviation is more noticeable (a system can also be configured to notify the user). Although this can also be deceiving if multiple sensors get a roughly equal deviation as time progresses. That is why checking with a known reference value is also important.

10 Self-assembly modules versus ready-to-use products

It is advisable for vegetable garden de Haar to buy smart products that are for the most part ready-to-use. Other names for this are also called 'plug & play' and 'off the shelve'. Within the practice of automation, custom-made modules with sensors are also widely used. When looking up information about automation in greenhouses, such self-build modules often come up and, despite the fact that they are not recommended for vegetable garden de Haar, it is still good to touch on them in this document.
It is good to recognize this way of working and thus understand that these are horticulturists with electrical engineering knowledge themselves or who hire someone to manage this equipment. In most cases, the same can be achieved with products that fall more into the 'plug & play' category. So when stumbling on such modules while looking for information, do not experience such modules as that garden automaton always is very complicated or only for those with high technical knowledge.

Advantages of a self-built module are the low cost and the possibility to create a design that fully meets all requirements. Nevertheless, such self-build modules are not recommended for Vegetable Garden de Haar. Such modules require a lot of specialist knowledge and if there are any problems or defects, a technician must be called in. Whereas with ready-to-use products, they can be replaced more easily by a grower himself to get the system working again.

Microcontrollers are often used for these self-assembly modules with sensors, both in the commercial and hobby domains. Microcontrollers (MCU) are small devices/circuit boards on which a piece of programming code can be loaded from a computer.

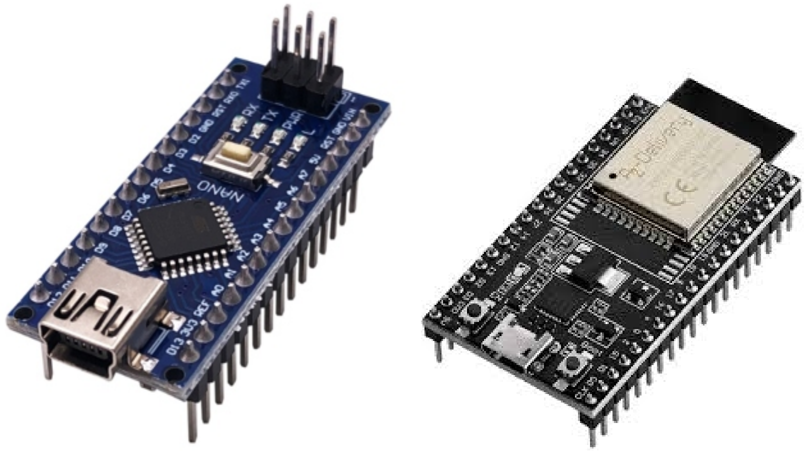


Image 30: Microcontrollers, in this case the Arduino Nano and to the right of it an ESP32

An example of someone who applies self-built modules within automation in the field of growing vegetables are the applications on the youtube channel[16] of the LED Gardener, Link. Image 31 shows a control cabinet built by him.

In his situation, he is both the hobbyist who designs the electronics himself and a grower of vegetables. If there is a defect in the electronics, he has the knowledge and skills to solve it himself. This is a different situation than in Vegetable Garden de Haar, where that knowledge is not available, but fortunately the same activity can also be achieved with plug & play modules.

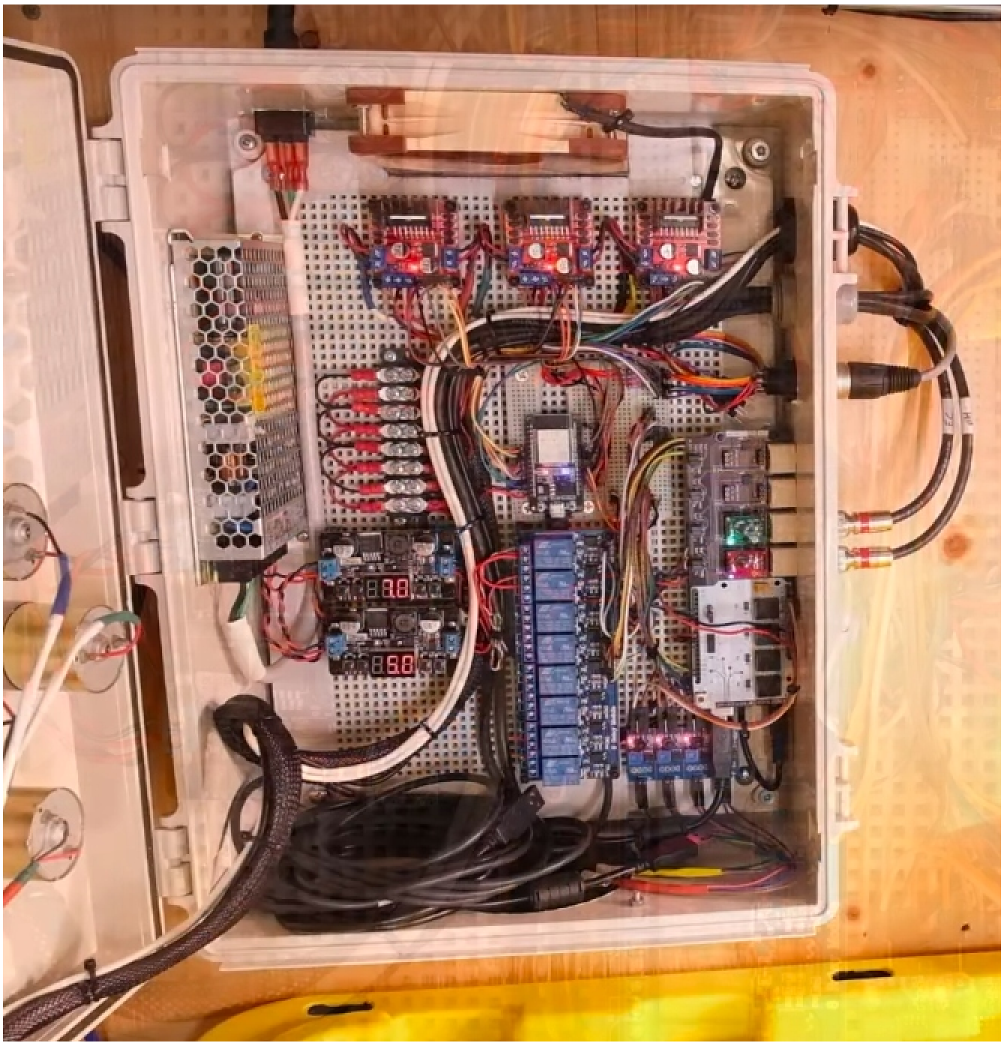


Image 31: An image from a video by youtuber LED Gardener, showing his self-built modules that process the sensor readings and turn devices on and off.

In the middle of Image 31 an ESP32 microcontroller can be seen. The ESP32 has all kinds of IO pins that receive sensor values and control relays to turn devices on or off.

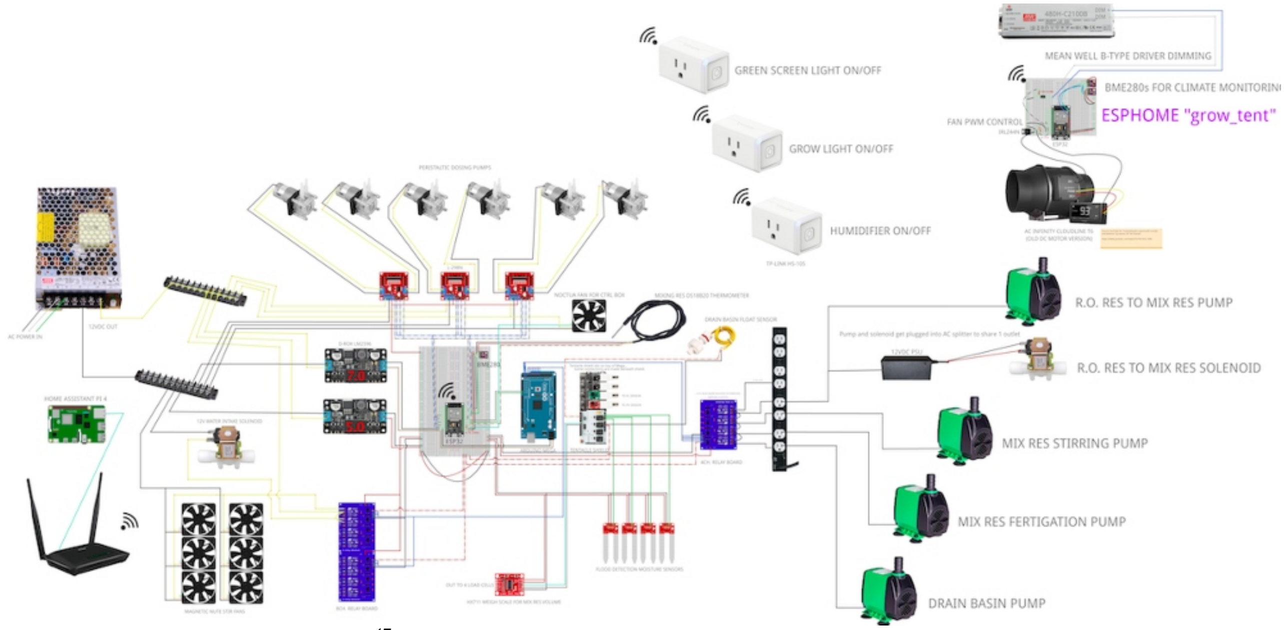


Image 32: Schematic illustration[17] of the control box designed by LED Gardener as shown in Image 31.

The LED Gardener uses Home Assistant as a central server and dashboard to monitor and control its system (Home Assistant is discussed in paragraph 6.3.2). In his case, Home Assistant runs on the Raspberry PI minicomputer, visible in Image 32.

As mentioned earlier, a system with the same effect can also be put together with ready-to-use modules.

For example, the part of the LED gardener's system that controls the pumps could also be implemented with the devices in Image 33.

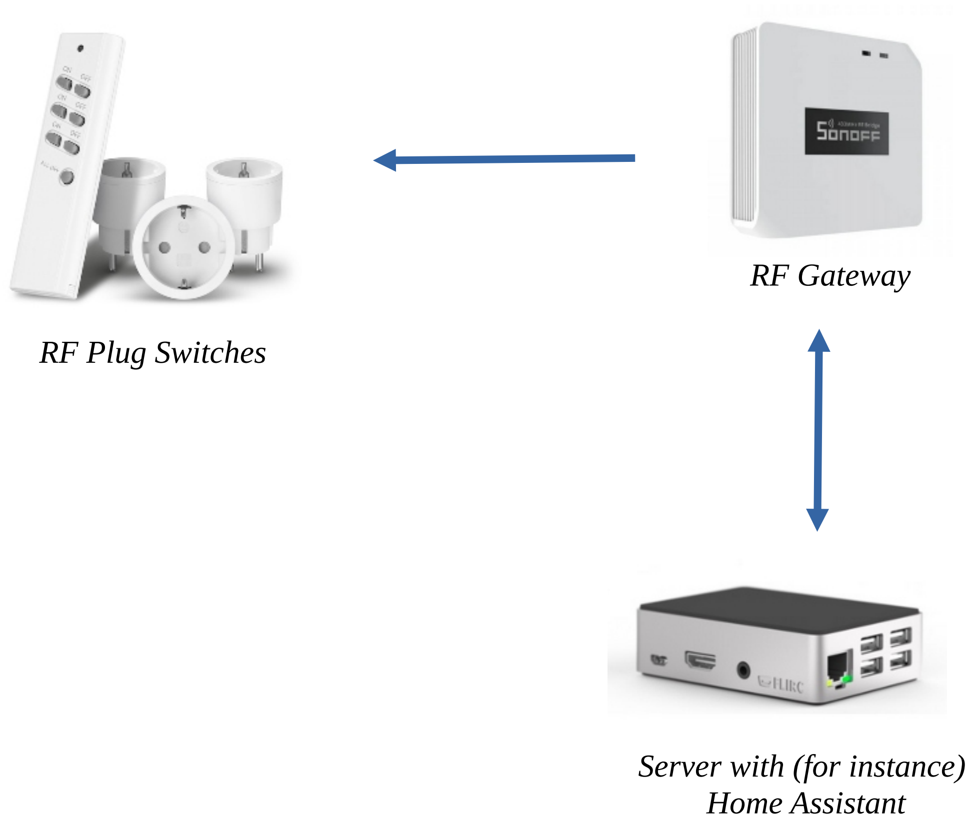


Image 33: Example of an alternative to part of the LED Gardener design, using off-the-shelf products such as RF plugs and an RF gateway.

Another video found on YouTube of a horticulturist[18] whose greenhouse has been automated using self-designed modules is the following:

Link: [Arduino Greenhouse mrk 2]

That video is a bit older and therefore extra impressive to see what this horticulturist has made.

There are some interesting tips in it to see how this horticulturist has handled certain things. For example, he used a tube with a black casing at the top and a white bottom. Because the black color absorbs light, it becomes warmer at the top and as a result there will be airflow, which provides a more representative reading, as non-moving air will be less representative.

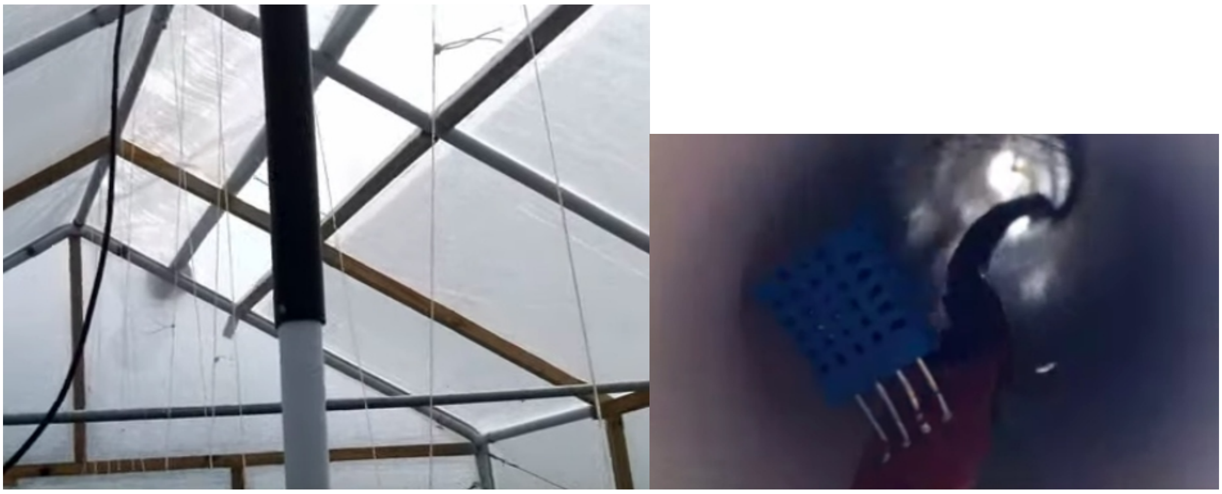


Image 34: White tube with black casing on the top. On the right side the temperature sensor is mounted in the tube. Images from video Instrumenttek.

11 Measuring and controlling temperature

11.1 Background

The temperature of the environment is important for the growth of a plant. Depending on the type of plant, there are certain extremes that should not be reached under any circumstances, such as deep frosts or very high temperatures. And in addition, there will be an optimal range of temperature values within which the temperature can remain the best for that plant.

EXIGENCIAS DE TEMPERATURA PARA DISTINTAS ESPECIES

Tª MÍNIMA LETAL	0-2	(-1)	-	(-1)	0-1	0
Tª MÍNIMA BIOLÓGICA	11	11	11	11	13-15	12
Tª ÓPTIMA	13-16	13-18	17-22	18-18	18-21	17-20
Tª MÁXIMA BIOLÓGICA	21-27	23-27	22-27	20-25	25-30	23-28
Tª MÁXIMA LETAL	33-38	33-35	43-53	31-35	33-37	33-37

Image 35: Table of optimum temperatures and limit values for different vegetables[19]

There can also be an optimal temperature for each growth phase of a plant.

11.2 Determining the temperature

It can be advantageous for the horticulturist to know the temperature of the outside air as well as that in the greenhouses. In the following sections, we will discuss how these temperatures can be determined. Ranging from simple ways to methods of measuring that can be included in a design of an automated way.

11.2.1 The outside temperature

It is useful to determine the outside temperature so that a picture can be obtained of the temperature development over a longer period of time. With this data, the grower can, for example, look back at the temperature trend and use this influence as an explanation of the yield and quality of a particular crop.

Also, if the outside temperature and the temperature in greenhouses are known, they can be compared. From this it can be determined whether it makes sense to ventilate (possibly automatically) in the greenhouse and what maximum temperature can be achieved by ventilating in the greenhouse. The maximum temperature that can be achieved in the greenhouse through ventilation is the temperature of the outside air.

Determining the outside temperature can be done in different ways. From simply using a readable thermometer (Image 36) to a digital sensor, possibly incorperatd in an advanced configuration with a server.

Image 36: Traditional thermometer

The digital form can be via a weather station:

Image 37: Example of a weather station[10]

Or, if a more advanced system is desired, with a server (Chapter 6), in which the values can be used as a basis for automations, then LoRaWAN devices seem very suitable, such as this one from Dragino:

Image 38: Dragino S31B-LB - LoRaWAN Temperature & Humidity Sensor[11]

Or the LoRaWAN weather station

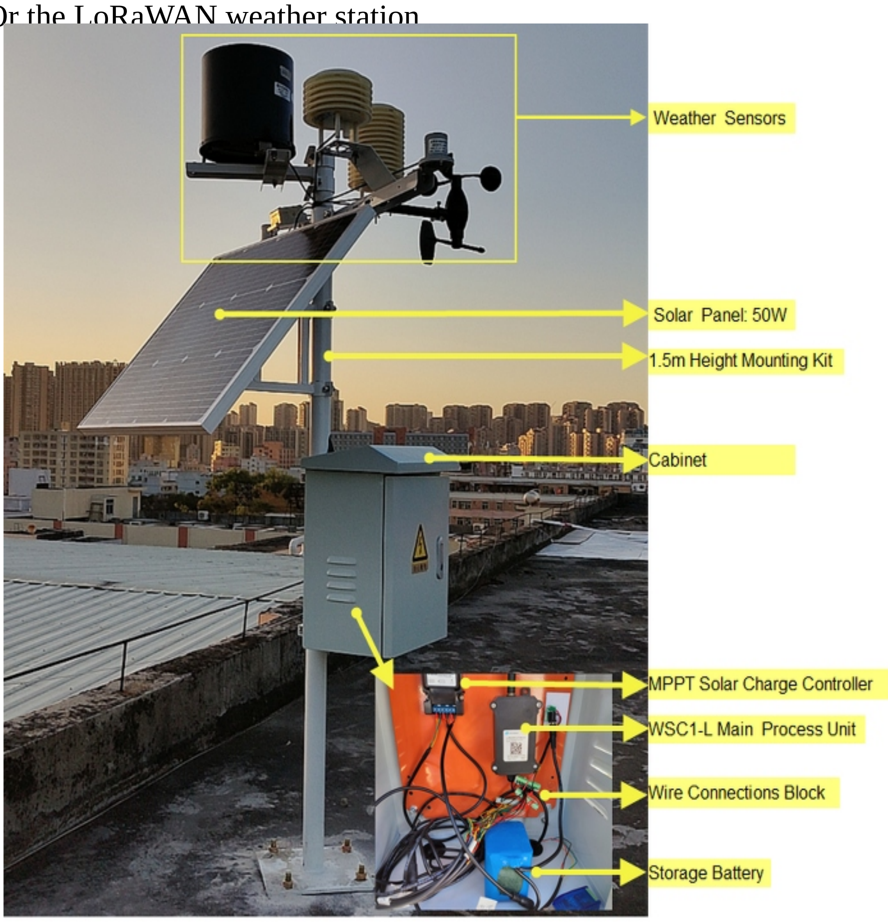


Image 39: Example of a configuration with the Dragino LoRa basic module for weather stations with various modules.

11.2.2 Determining the temperature in the greenhouse

Thermometers similar to those used for the outside temperature can be used to determine the temperature in the greenhouse. Ranging from manual (Image 36) to a multi-feature solution that can be incorporated into an automation system (Image 37)

11.2.3 Automating temperature control in the greenhouse

When controlling the temperature in the greenhouse, there will also be an influence on the humidity, which is why it seems a good idea to consider both the humidity and the temperature when ventilating, in order to make both values as optimal as possible. It is therefore good to refer here to paragraph 12.2.2 Automatic ventilation for better humidity, where both influences are taken into account. The extension to active ventilation (with fans) is also discussed in that section.

Below, we will discuss some more methods if it is only kept to ventilation based on temperature values.

The easiest way to control the temperature in the greenhouse is to control the ventilation yourself by opening or closing doors.

A step further is to use a thermostat-like solution, where ventilation is opened based on temperature.

An easy-to-use method that does not require electricity with Automatic openers of greenhouse windows, which work with cylinders. The heat in the greenhouse heats up a liquid in a cylinder. Expansion takes place and a mechanism is set in motion so that the window is opened at about 24 degrees. The windows close at 15 degrees when the cylinder cools down and shrinkage occurs. See images 40 and 41. However, it should be mentioned that it only controls the temperature, and not the humidity.

Image 40: Automatic greenhouse room opener with cylinder

Image 41: Louvre window with automatic opening by means of cylinder

The disadvantage of using these automatic window openers with cylinders is that they do not work very delicately. There are fixed limit values at which they open and close, which can prevent temperatures in the greenhouse from being too high, but they are not suitable for regulating an optimal temperature value.

A step further is to control roller motors or window openers with a thermostat[20] as in Image 42. This is a standalone application that is relatively simple in nature. At the same time, measuring the temperature is not very subtle, because there is only one measuring point where several measuring points in the greenhouse would be better. Remote control and more advanced automation are not possible here. Furthermore, the humidity is not taken into account.

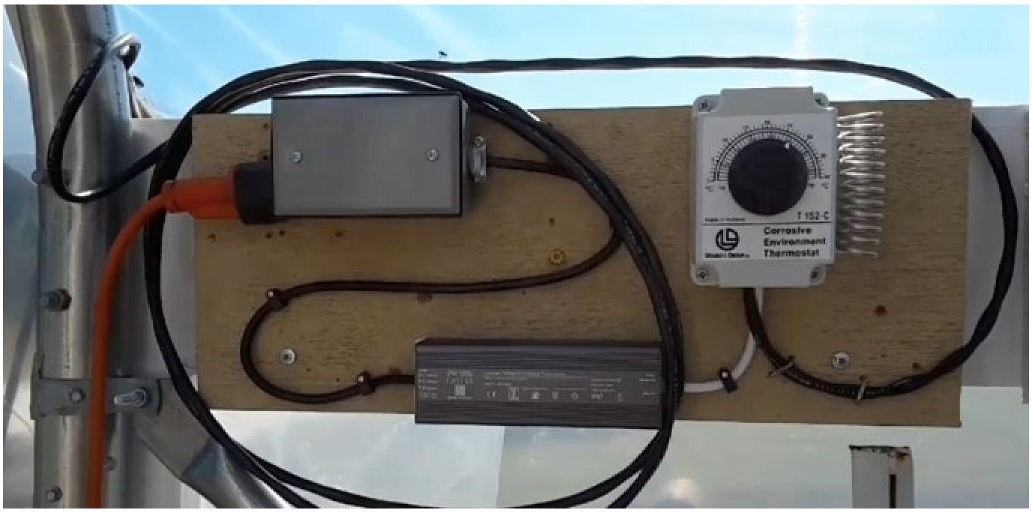


Image 42: Thermostat for opening roller motors20

The thermostat can switch the roller motors that roll up the plastic of the tunnel greenhouse (Image 43 and Image 44) or a form of window opening, (Image 45).

Image 43: Close up of a roller motor that can roll up the tarpaulin of a tunnel greenhouse

Image 44: Roller motor for a tunnel greenhouse that is equivalent to the greenhouses at Vegetable Garden de Haar[21]

Image 45: Louvre window in greenhouse that can be opened and closed with electric control. Form of passive ventilation.

Another step further is the measurement and control of the temperature using a configuration with a server (Chapter 6) which controls the roller motors or similar louvered window . In that case, there is an institution equivalent to that described in paragraph 12.2.2 Automatic ventilation for better humidity.

For that application, some kind of switch will have to be included in the system.

It is possible, for example, to have the roller motors or other window openers controlled in a control cabinet.

Image 46: Smart plug that can be included in a circuit with a server

Or in a wireless configuration (WiFi, RF, LoRa) it may also be possible to use smart plugs. For example, they might look like this:

Image 47: Smart plug that can be included in a circuit with a server

The advantage of such a plug could be that it is relatively easy to replace it by the grower himself in the event of a defect.

12 Measuring and controlling humidity

For humidity control it is important to understand the concepts Relative humidity, absolute humidity and Vapour Pressure Deficit and how to determine the desired values. Therefore this chapter starts with some background on these subjects.

12.1 Background

Humidity has an influence on the growth of a plant. It is known that excessive humidity can increase the growth of mould. Too low humidity is also not good. There is an optimal range of humidity.

Role of Humidity

The main plant mechanism to cope with humidity is the adjustment of the leaf stomata. Stomata are pores in the underside of the leaf that open and close in response to vapour pressure deficit. When humidity levels drop to about 8 grams/m^3 (12 mb VPD) the stomata apertures on most plants close to about 50% to help guard against wilting. This also reduces the exchange of $C0_2$, thereby negatively affecting photosynthesis.

Image 48: Brief description of the importance of humidity for optimal photosynthesis. Screenshot from PDF document "Understanding Humidity Control in Greenhouses" from the Canadian government[36]

Air can absorb more water as the temperature increases. This is illustrated in Image 49.

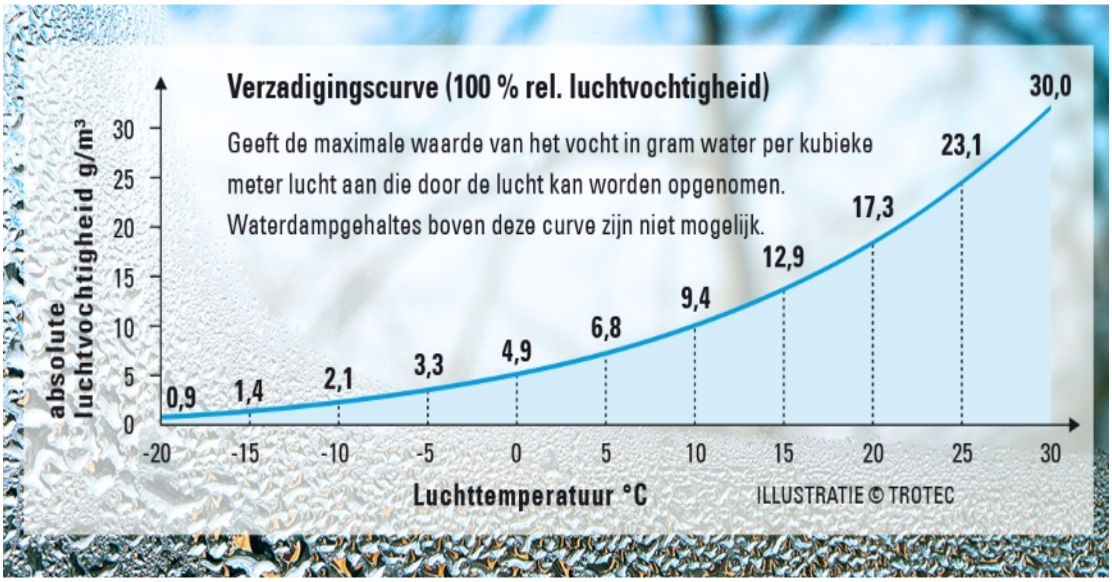


Image 49: Maximum amount of water in the air (g/m^3) at various temperatures

12.1.1 Relative humidity

One of the ways to express humidity is in the percentage of relative humidity. Air can hold a maximum amount of water, then the air is saturated. The maximum amount of water that can be absorbed into the air depends on the temperature. At higher temperatures, more water can be absorbed.

Relative humidity is the part of the maximum amount of water that the air can hold at the temperature that prevails at that time. Expressed as a percentage.

In formula, you can write that as follows:

$$\text{relative humidity} = \frac{\text{amount of water in the air}}{\text{maximum amount of water the air can contain at the current temperature}} * 100\,\%$$

At 100% relative humidity (saturated), the air can no longer absorb water. When saturated air cools, condensation occurs. Think of the condensation on the grass in the morning. During the night, the temperature has become lower and where the air can still contain a large amount of water during the day, it is less so when the temperature decreases. The water has condensed.

It is also noticeable in the home. At a humidity of above 60% for a longer period of time, things sometimes feel damp. Mould also forms on the walls if there is a prolonged high relative humidity.

If the outside air has a higher relative humidity than inside, ventilation may still make sense. The temperature plays a role. If, compared to the interior, colder air with a higher relative humidity is brought in, it may be that the relative humidity inside does indeed drop.

In order to compare, it is therefore better to also look at other expressions of humidity, such as the absolute humidity, described in paragraph 12.1.2 or the target value of Moisture Deficit / VPD, paragraph 12.1.3 .

12.1.2 Absolute humidity

Humidity can also be expressed in absolute humidity. The amount of water in the air is expressed in grams of water per cubic meter of air, g/m^3.

It can happen that a room is closed and has a certain absolute humidity, for example a greenhouse with doors closed. If the temperature of that room increases, then the percentage of *relative humidity will* decrease, but the absolute humidity (g/m^3) will remain the same. And also the other way around, if the temperature drops at the same absolute humidity, the relative humidity will rise.

If the temperature in the greenhouse drops, for example during the night, the relative humidity can become higher than desired for the plants present. It may then be desirable to apply some form of ventilation. It would be possible to automate this.

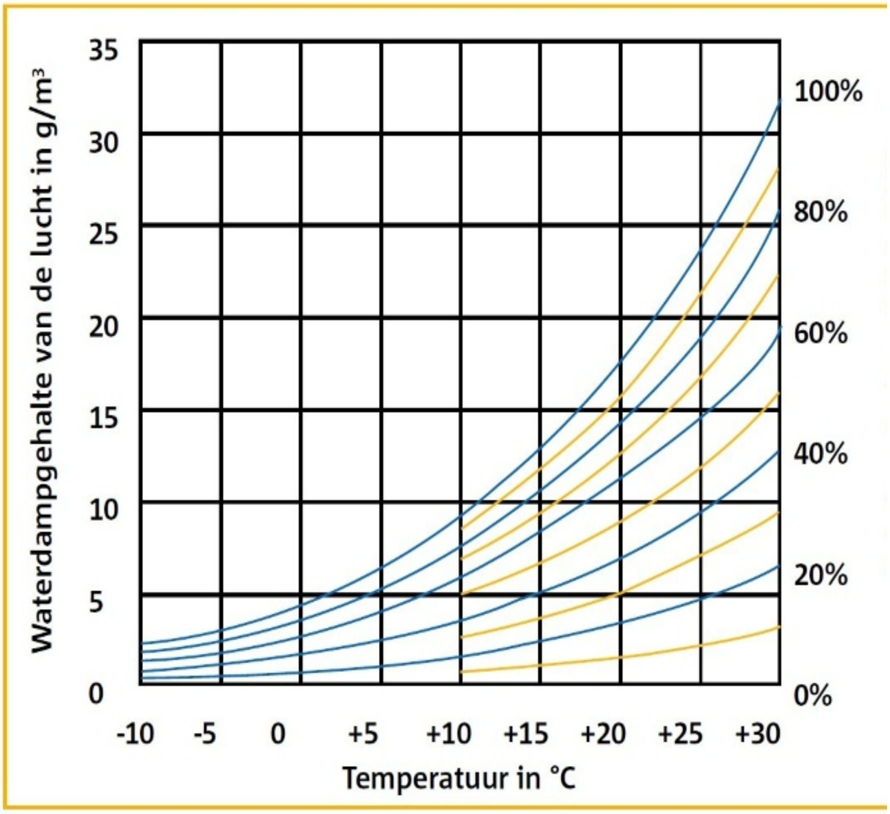


Image 50: Absolute humidity in g/m^3 at different percentages of relative humidity

12.1.3 Moisture Deficit and Vapour Pressure Deficit as a target value

Another way of expressing humidity is in humidity deficit. On the website of greenhouse automation company Orisha, there is an article[22] described about the moisture deficit, **link**

The moisture deficit is the number of grams of moisture per m^3 of air that can still be added to the air before it is saturated.
The advantage of using moisture deficiency as a target value for a plant for the humidity in a greenhouse is that this value remains the same with changing temperature. This is in contrast to the target value expressed in percentage relative humidity, which will change as the temperature changes. When using relative humidity, an intermediate step is therefore required to determine whether the humidity is within the desired range. When using moisture deficiency, that extra step is not necessary. See also the screenshot from **Link** in Image 52.

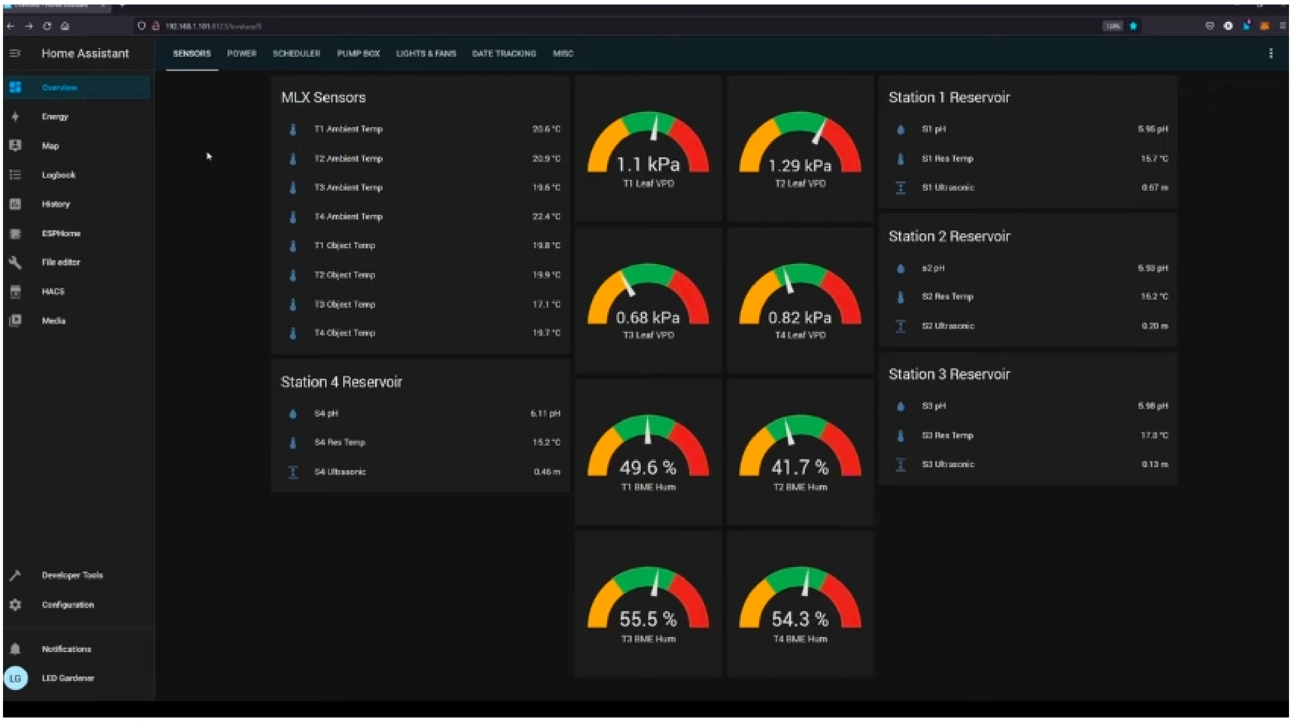


Image 51: Charts for VPD values have been added to this dashboard, with corresponding colors to indicate whether the correct range has been maintained. Dashboard is created with the software Home Assistant as used by youtuber LED Gardener8

Advantages of Managing the Humidity Deficit

When we use Relative Humidity, the optimal interval for the plants changes with the temperature. By using the Humidity Deficit, the interval stays the same without any regard for temperature variation. This can simplify greenhouse climate management.

Temperature	15°C	20°C	30°C
RH management	50-75%	60-80%	80-90%
DH management	3-7 g/m3	3-7 g/m3	3-7 g/m3

The RH is not telling us the direct effect on the plant. 80% relative humidity is good for the plant at 20°C but too humid at 15°C. Because you need to factor in the temperature with the relative humidity reading makes evaluating optimal growing conditions harder.

Image 52: The benefits of using humidity deficit as a target, screenshot from Orisha's blog post on this topic (VPD).

Vapour pressure deficit
Another commonly used expression of humidity in greenhouses is Vapour Pressure Deficit

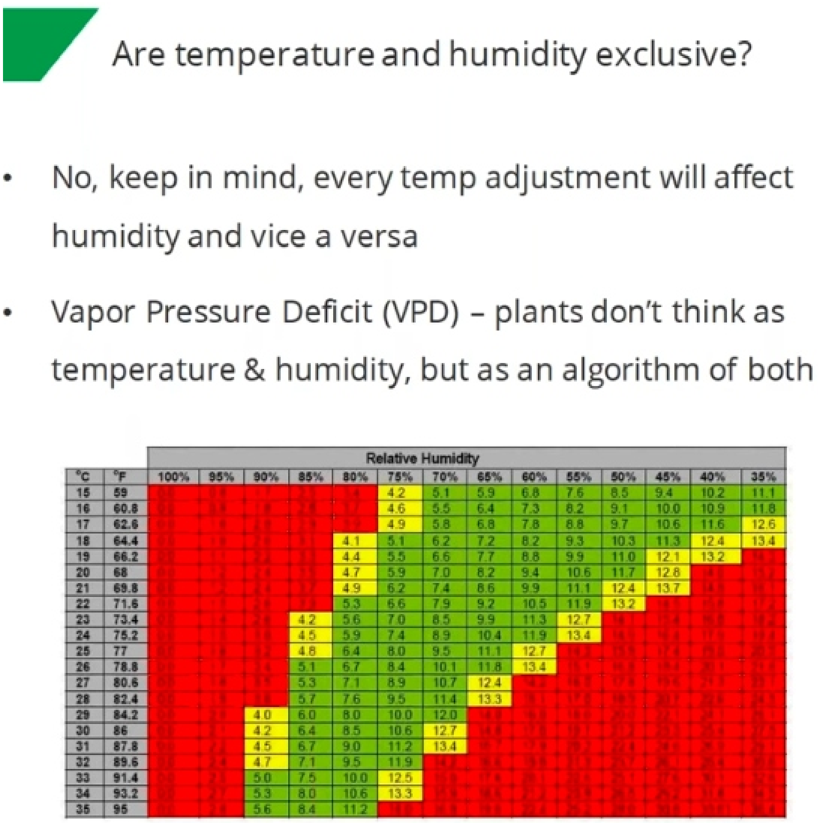
VPD seems to be used in a lot of literature, which makes it useful to look up the optimal values. VPD is another way of expressing the fluid deficit. VPD is not expressed in g/m^3, but in kPa, i.e. in pressure. There are many sources[23,24] on it that write about Vapour pressure deficit, for example in this article site of Drygair or in an article on Wikipedia. Within the vapour pressure deficit, the temperature of leaves is sometimes also taken into account.

A YouTube video[25] covering VPD: Link.

12.1.4 Optimal humidity for plants

An extensive video[26] on the topic of humidity and plants in greenhouses can be found on Youtube from the company Autogrow, **link**.

From this video from Autogrow comes the screenshot below, Image 53. It contains a table with VPD values for temperature and relative humidity. An equivalent table can be seen in Image 54. For most plants, it is desirable to stay within the green area in the table.



		Relative Humidity													
°C	°F	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%
15	59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.2	5.1	5.9	6.8	7.6	8.5	9.4	10.2	11.1
16	60.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.6	5.5	6.4	7.3	8.2	9.1	10.0	10.9	11.8
17	62.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.9	5.8	6.8	7.8	8.8	9.7	10.6	11.6	12.6
18	64.4	[illegible]	[illegible]	[illegible]	[illegible]	4.1	5.1	6.2	7.2	8.2	9.3	10.3	11.3	12.4	13.4
19	66.2	[illegible]	[illegible]	[illegible]	[illegible]	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2	[illegible]
20	68	[illegible]	[illegible]	[illegible]	[illegible]	4.7	5.9	7.0	8.2	9.4	10.6	11.7	12.8	[illegible]	[illegible]
21	69.8	[illegible]	[illegible]	[illegible]	[illegible]	4.9	6.2	7.4	8.6	9.9	11.1	12.4	13.7	[illegible]	[illegible]
22	71.6	[illegible]	[illegible]	[illegible]	[illegible]	5.3	6.6	7.9	9.2	10.5	11.9	13.2	[illegible]	[illegible]	[illegible]
23	73.4	[illegible]	[illegible]	[illegible]	4.2	5.6	7.0	8.5	9.9	11.3	12.7	[illegible]	[illegible]	[illegible]	[illegible]
24	75.2	[illegible]	[illegible]	[illegible]	4.5	5.9	7.4	8.9	10.4	11.9	13.4	[illegible]	[illegible]	[illegible]	[illegible]
25	77	[illegible]	[illegible]	[illegible]	4.8	6.4	8.0	9.5	11.1	12.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	78.8	[illegible]	[illegible]	[illegible]	5.1	6.7	8.4	10.1	11.8	13.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	80.6	[illegible]	[illegible]	[illegible]	5.3	7.1	8.9	10.7	12.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	82.4	[illegible]	[illegible]	[illegible]	5.7	7.6	9.5	11.4	13.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	84.2	[illegible]	[illegible]	4.0	6.0	8.0	10.0	12.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	86	[illegible]	[illegible]	4.2	6.4	8.5	10.6	12.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	87.8	[illegible]	[illegible]	4.5	6.7	9.0	11.2	13.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	89.6	[illegible]	[illegible]	4.7	7.1	9.5	11.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
33	91.4	[illegible]	[illegible]	5.0	7.5	10.0	12.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
34	93.2	[illegible]	[illegible]	5.3	8.0	10.6	13.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
35	95	[illegible]	[illegible]	5.6	8.4	11.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Image 53: Screenshot from video of Autogrow with table optimal VPD per temperature

https://www.GlobalGarden.co/

Temperature		Relative Humidity											
C	F	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%
15	59	1.7	2.6	3.4	4.3	5.1	6.0	6.8	7.7	8.5	9.4	10.2	11.1
16	61	1.8	2.7	3.6	4.5	5.5	6.4	7.3	8.2	9.1	10.0	10.9	11.8
17	63	1.9	2.9	3.9	4.8	5.8	6.8	7.8	8.7	9.7	10.7	11.6	12.6
18	64	2.1	3.1	4.1	5.2	6.2	7.2	8.3	9.3	10.3	11.4	12.4	13.4
19	66	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2	14.3
20	68	2.3	3.5	4.7	5.8	7.0	8.2	9.4	10.5	11.7	12.9	14.0	15.2
21	70	2.5	3.7	5.0	6.2	7.5	8.7	10.0	11.2	12.4	13.7	14.9	16.2
22	72	2.6	4.0	5.3	6.6	7.9	9.3	10.6	11.9	13.2	14.5	15.9	17.2
23	73	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6	14.1	15.5	16.9	18.3
24	75	3.0	4.5	6.0	7.5	9.0	10.4	11.9	13.4	14.9	16.4	17.9	19.4
25	77	3.2	4.8	6.3	7.9	9.5	11.1	12.7	14.3	15.8	17.4	19.0	20.6
26	79	3.4	5.0	6.7	8.4	10.1	11.8	13.5	15.1	16.8	18.5	20.2	21.9
27	81	3.6	5.4	7.1	8.9	10.7	12.5	14.3	16.1	17.8	19.6	21.4	23.2
28	82	3.8	5.7	7.6	9.5	11.3	13.2	15.1	17.0	18.9	20.8	22.7	24.6
29	84	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.1
30	86	4.2	6.4	8.5	10.6	12.7	14.9	17.0	19.1	21.2	23.4	25.5	27.6
31	88	4.5	6.7	9.0	11.2	13.5	15.7	18.0	20.2	22.5	24.7	27.0	29.2
32	90	4.8	7.1	9.5	11.9	14.3	16.7	19.0	21.4	23.8	26.2	28.6	30.9
33	91	5.0	7.6	10.1	12.6	15.1	17.6	20.1	22.7	25.2	27.7	30.2	32.7
34	93	5.3	8.0	10.6	13.3	16.0	18.6	21.3	24.0	26.6	29.3	31.9	34.6
35	95	5.6	8.4	11.3	14.1	16.9	19.7	22.5	25.3	28.1	31.0	33.8	36.6

Image 54: Table of VPD values in kPa at different temperatures, the values with green shading are within the optimal range[27]

From the table in Image 54 It can be seen that at 17°C the optimal relative humidity is between 45% and 60%. At 29°C, the optimal relative humidity is between 75% and 80%. The grower can target the VPD between 7.5 kPa and 10.5 kPa, regardless of the temperature.

12.2 Achieving the optimal humidity in the greenhouse

For plants that grow in the open air, the humidity can be measured and acted upon. But especially in the greenhouse, the humidity can be influenced well. In the following sections, we will discuss how the humidity in the greenhouse can be monitored and adjusted.

12.2.1 Determining the humidity of the outside air

To determine whether it is useful to ventilate, it is necessary to determine the humidity and temperature of the outside air. To compare this with the humidity in the greenhouse. This can be done with different products.

A simple solution can be to place an outdoor sensor and read it and use it to manually control the ventilation based on that. This could be done with products such as in Image 55 and Image 56.

Image 55: Outdoor Temperature & Humidity Sensor

It can also be done with a weather station. A weather station often offers more values such as temperature, wind speed and number of mm of rainfall. So that can be a nice all-in-1 solution.

In addition to this manual way, a more advanced way can also be chosen. With a sensor that is included in a system where the process of air control can be automated. Think, for example, of the automatic opening of windows and possibly turning on fans, depending on how the humidity values in the greenhouse are compared to outside.

Image 56: Example of a weather station

This can be achieved in a system with sensors that can be read in a system with a central server (see chapter 6). The server reads the sensors and starts and stops actions to influence humidity.

The products with LoRa connection (discussed separately in chapter 7) seem very suitable to use in such a system in the garden. These work wirelessly over a long distance and use little energy.

For example, the Dragino S31B-LB, seen in , link to manufacturer's website.
This is a measuring point with LoRa communication with a battery life of up to 5 years.
For sale at Antratek.nl for €62,86 each, link.

Image 57: Dragino S31B-LB - LoRaWAN Temperature & Humidity Sensor

Dragino also offers a node to which various weather station modules can be connected. The basic module does not seem to be for sale in the Netherlands, but can be seen on Aliexpress for €80, link.

Various modules can be connected to this to form a weather station.

Image 58: Dragino WSC2-LB, the main process unit for Dragino weather station.

For example, there is the WSS-05 -- Temperature/Humidity/Illuminance/ Pressure module. Featured in in Image 59. This has a canopy that better shields the sensors from rain and wind, which provides a more reliable measurement of the conditions in the air. In addition to temperature and humidity, it also offers light intensity and air pressure.

Image 59: Dragino WSS-05 -- Temperature/Humidity/Illuminance/ Pressure module.

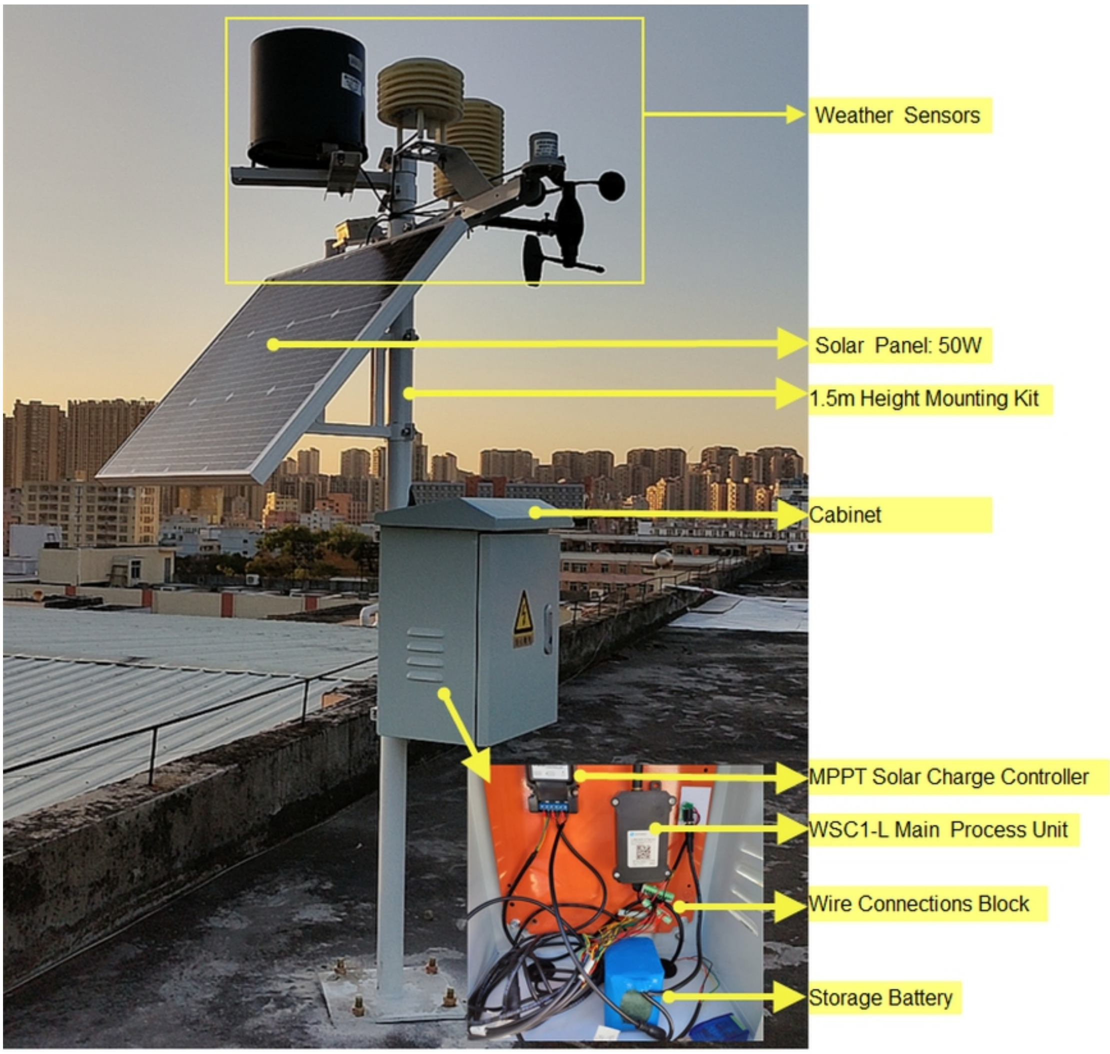


Image 60: Example of a configuration with the Dragino LoRa basic module for weather stations with various modules.

12.2.2 Automatic ventilation for better humidity

If the humidity of the outside air and the air in the greenhouse is known, it is possible to take actions to achieve the ideal humidity for the crops currently in the greenhouse.
To achieve this, ventilation can be started with outside air. When ventilating, the temperature in the greenhouse will also be influenced, depending on the outside temperature. Furthermore, there is a dependence on the level of humidity outside, whether it is possible that the ideal range of humidity can be achieved through ventilation. So it is a combination of both the outside temperature and the

humidity outside when it comes to trying to achieve the desired temperature and humidity in the greenhouse.
Besides ventilation, other ways to influence humidity include the use of electric dehumidifiers or humidifiers. These are other solutions that are possible in addition to ventilation that can be considered if in practice it appears that optimal conditions cannot often be achieved. There may be situations where it is better to use a dehumidifier instead of ventilation.

12.2.2.1 Passive and active ventilation

A distinction can be made between passive and active ventilation. Passively, it is the natural air flow that occurs when opening a door or window. Active ventilation is ventilation that uses a device to increase airflow.

Opening shutters or rolling up the tarpaulin of a tunnel greenhouse are forms of passive ventilation.

This can be carried out electrically with applications visible in Image 61, 62 and 63. These electrical applications can possibly be included in an automation system based on temperature and humidity.

Image 61: Louvre window in greenhouse that can be opened and closed with electric controls. Form of passive ventilation.

In Image 61 a 'Louvre window' is visible with a motor that automatically opens and closes the shutters. This fits better in a situation where the humidity can also be controlled.
Another option for passive ventilation is to roll up the tarpaulins of the tunnel greenhouses. The greenhouses are currently also equipped with a mechanism to roll up the sails by hand. Using roller motors like these can also immediately take care of manual rolling up.

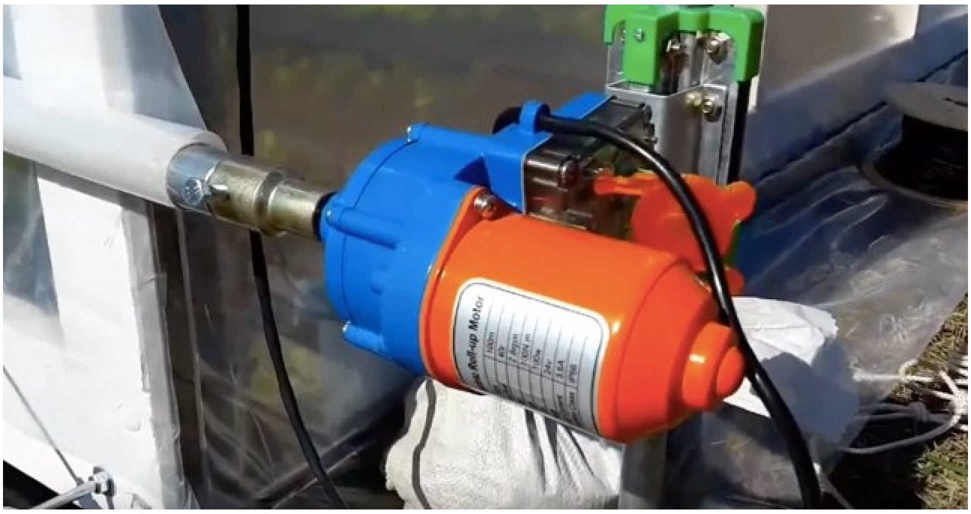


Image 62: Close-up of a roller motor that can roll up the tarpaulin of a tunnel greenhouse

Image 63: Roller motor for a tunnel greenhouse that is equivalent to the greenhouses at Vegetable Garden de Haar

By using fans, passive ventilation, caused by opening shutters or rolling up tunnel tarpaulin, can be expanded to active ventilation.

The following images show forms of active ventilation:

Image 64: Louvre shutters met ingebouwde ventilator

The built-in fan in the image Image 64 provides greater airflow.

Afbeelding 65: Ventilator in kas

Circulation
The fans as in Afbeelding 65 In addition to ventilation, they can also provide circulation of air in the greenhouses. This can provide better growing conditions because it prevents local differences in the air around the plants from occurring. The concentration of CO_2, necessary for photosynthesis, can then improve around the leaves. More circulation may also help to prevent the plants from becoming too warm.

Much of the information in this section comes from a blog[28] from the University of Vermont. In that blog article, link, desired air movement values are also stated and how these can be calculated and what fan size is required.

Automatically switching ventilation actuators
To operate the shutters, roller motors and fans, some form of switches will have to be included in the system.
It is possible to control the roller motors or other window openers in a switch box.

Or in a wireless configuration (WiFi, RF, LoRa) it may also be possible to use smart plugs. For example, they could look like this:

Image 66: Smart plug that can be included in a circuit with a server

The advantage of such a plug could be that it can be replaced relatively easily by the horticulturist himself in the event of a defect.

12.2.3 Control ventilation automatically

As described earlier, the ventilation of greenhouses involves an interplay between outside temperature, humidity of the outside air and humidity of the air in the greenhouse.

It will sometimes be quite difficult to maintain optimal humidity and also keep the temperature within the desired values. Simply opening a window every time the humidity in the greenhouse is too high or too low does not seem like a good idea. Because every time you ventilate, cold air will also enter the greenhouse and this can be at the expense of maintaining the desired temperature. The question is also whether ventilation makes sense if there is high humidity outside.

This also applies to controlling the temperature. Ventilation to lower the temperature is possible to achieve higher humidity, higher than that which may be desired.

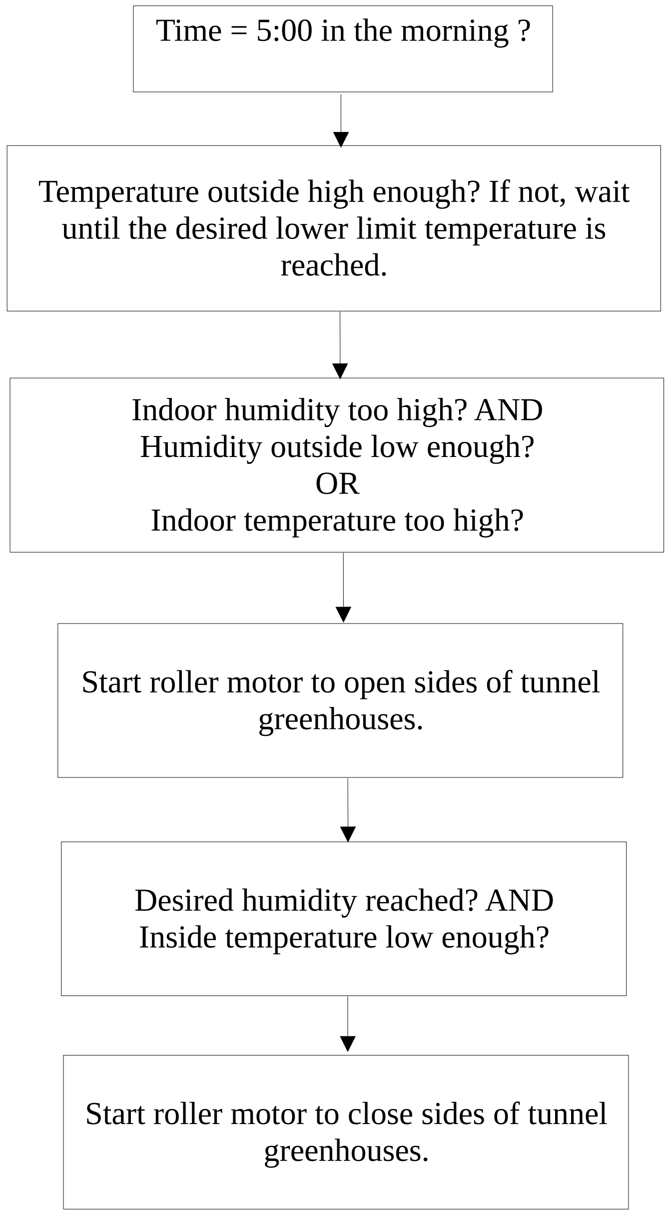
It goes too far for this report to present a perfectly working configuration on how to go about it, but during the orientation a number of sources came along that talked about following certain ventilation cycles. This means that you go through a certain cycle every day to stay within the desired range of temperature and humidity values.

It seems useful to use the early morning for ventilation. In the morning the outside temperature is at its lowest and therefore the absolute humidity is often at a low point, because cooling air condenses during the night and therefore decreases in moisture content (in absolute terms). If the measured values show that it would be a good idea to reduce the humidity, ventilation can be started in the morning. The advantage is that dry air can then be introduced into the greenhouse. The greenhouse can then be closed again and the temperature will rise during the day as a result of the sunlight entering the greenhouse.

When setting up an automation, there is usually one or more triggers, conditions and actions on the basis of which the automation is completed. It is possible to represent such automation schematically.

The trigger could be 5:00 in the morning. One condition is the outside temperature. And if it makes no sense for the humidity, it is also useful to postpone ventilation.

In schematic form it looks like this:



This is just a sketch to give you an idea. More attention will have to be paid to achieving good automation for ventilation for optimal temperature and humidity.

13 Irrigation

It is possible to automate irrigation. The following components could be part of an automated irrigation system.

Electric valves can be used to open or close a water supply:

Image 67: Electric valve that can be incorporated into an automated circuit[29]

With a distributor and valves, several irrigation zones can then be controlled, such as these:

Image 68: Distributor with electric valves for irrigation

Flow meters, which measure the volume of water flowing through per minute, can be used to check how much water has been sprayed and can also act as a control mechanism to remotely determine whether there is really water flow.

Image 69: Dragino LoRaWAN Outdoor Flow Sensor[30]

An application with telescopic nozzles, which rise on their own at water pressure, can also come in handy in such a system.

Image 70: These telescopic sprinklers rise when water pressure is applied[31,32]

There is also the possibility to measure the soil moisture and control accordingly. There are various forms of soil moisture sensors, including these:

Image 71: Renke tensiometer with connectivity options (RS485 modbus)[33]

The tensiometers are available in different lengths to measure at different depths in the earth, as illustrated in Image 72:

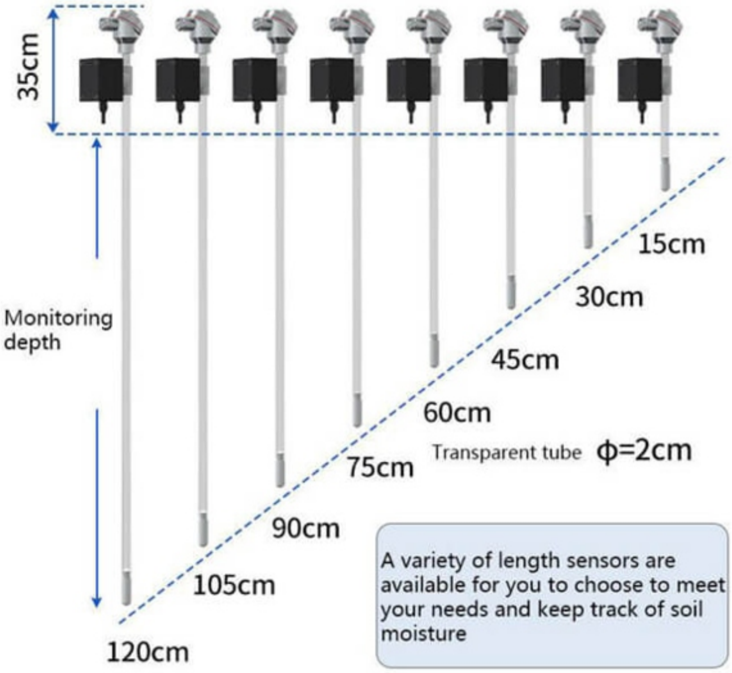


Image 72: Tensiometers come in different sizes[32]

Another form of a soil moisture sensor is:

Image 73: Soil moisture sensor with steel probes

The use of soil moisture meters does raise questions. The measurements are always a local measuring point, one question is whether it is representative of the entire field in which the sensor is placed. It is also not possible to assume that watering is evenly distributed over a field, so that control based on humidity meters may give a distorted picture.

At the same time, water does spread, which makes it more plausible that the measurement is representative. Multiple sensors can also be placed in a field for a higher reliability of the measurement. Further research on soil moisture sensors in combination with irrigation can provide information about the practice of working with irrigation controlled by humidity meters.

During the orientation, a web page of the Australian government[34] was found with a selection guide for soil moisture sensors, Link. There you can read more about soil moisture sensors.

14 Other possibilities for measuring and/or steering

In addition to the automation opportunities mentioned above in this report, other possibilities have been briefly mentioned in this chapter. In order to keep this report compact, these forms of automation have been briefly touched upon and not elaborated further.

14.1 Cameras for security and monitoring

There are conceivable applications in which cameras can be useful to view certain things in the garden remotely via internet browser or app on the phone. Sometimes it is more convenient to be able to observe through an image than with the help of a sensor.

Think, for example, of being able to see whether a door of a greenhouse has been opened or closed, whether irrigation is being carried out or if a flood sensor indicates that there is a water leak.

In addition, cameras can help with security. The garden is secluded and there are unsupervised moments. However, the issue of privacy comes into play. Not everyone may feel comfortable in the presence of cameras.

When using cameras with a remote connection, an internet connection with a high bandwidth is required, such as cable from Ziggo. That is more expensive than the mentioned option of a mobile internet subscription in paragraph 3.2 Internet connection.

In the Home Assistant dashboard (paragraph 6.3.2) are easy to record cameras.

14.2 Burglary alarm system

An anti-theft alarm system can be included within an automation system. Home Assistant (paragraph 6.3.2) offers built-in capabilities to do so.

14.3 Measuring and dosing CO_2

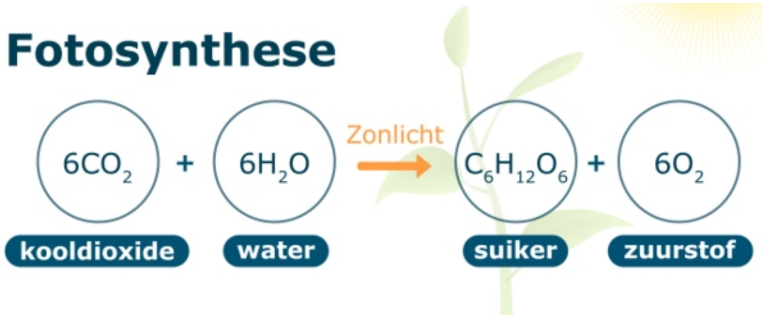


Image 74: The reaction equation for photosynthesis

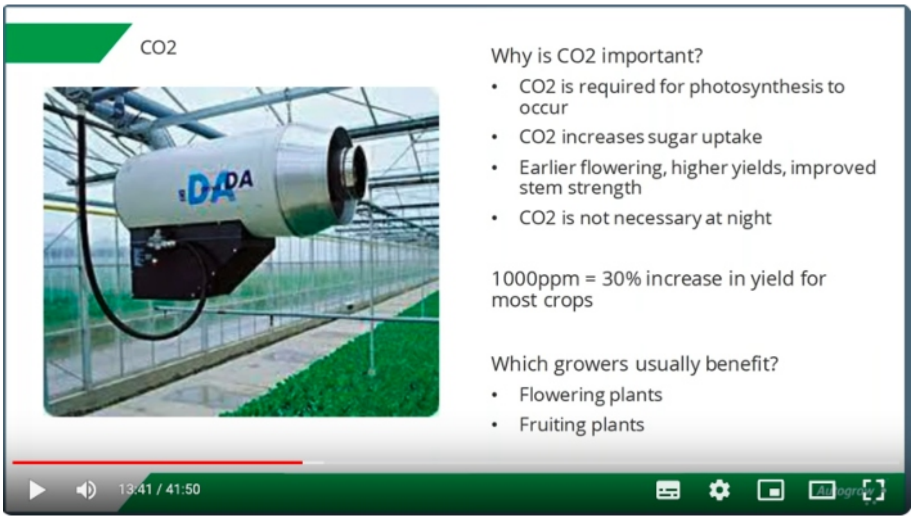
For a plant, CO_2 is a nutrient necessary for photosynthesis. The CO_2 content in the outside air is about 400 parts per million (ppm).

Each plant has an optimal amount of CO_2 for optimal growth. In a greenhouse, the CO_2 content can be measured and even adjusted with CO_2 dosing. This does fall under more advanced automation.

An example of a CO_2 sensor:

Image 75: ZyAura ZGm053U CO2 and temperature sensor.

On Autogrow's YouTube channel there is a video with more information about measuring and controlling CO_2 for plant growth:



Link: [Advanced Greenhouse Systems]

14.4 Automatically stretch a cloth over the greenhouse if there is too much heat

It seems conceivable that on very hot days it can be useful to stretch a cloth (motorized and automated) over the greenhouse, because ventilation does not lead to an improvement of the conditions in the greenhouse.

The videos below may provide inspiration for such applications.

Link: [Trinog greenhouse Inside shading screen system]

Link: How to Make a Slide-On Wire Hung Canopy (Pergola Canopy)

14.5 Optimising light in greenhouses with LED lamps

Light plays an important role in photosynthesis. The light in the greenhouses is transmitted through the plastic of the tarpaulin. This makes it weaker than light outside, and there are also shorter days in spring and autumn. This can be optimized with LED lamps.

Link: Best Grow Room Conditions For Maximum Yield - Light (PAR), Temperature and Air (CO_2)

I WISH I'd CHECKED This Earlier - Greenhouse LIGHT levels!

Link: I WISH I'd CHECKED This Earlier - Greenhouse LIGHT levels!

14.6 Measuring electricity consumption

It can be useful to provide insight into the power consumption, per day, per hour and/or per device. This can be done, for example, with CT clamps (to be installed by a professional), which measure the kilowatt hours through the clamped wire.

The CT clamps are visible in the image below:

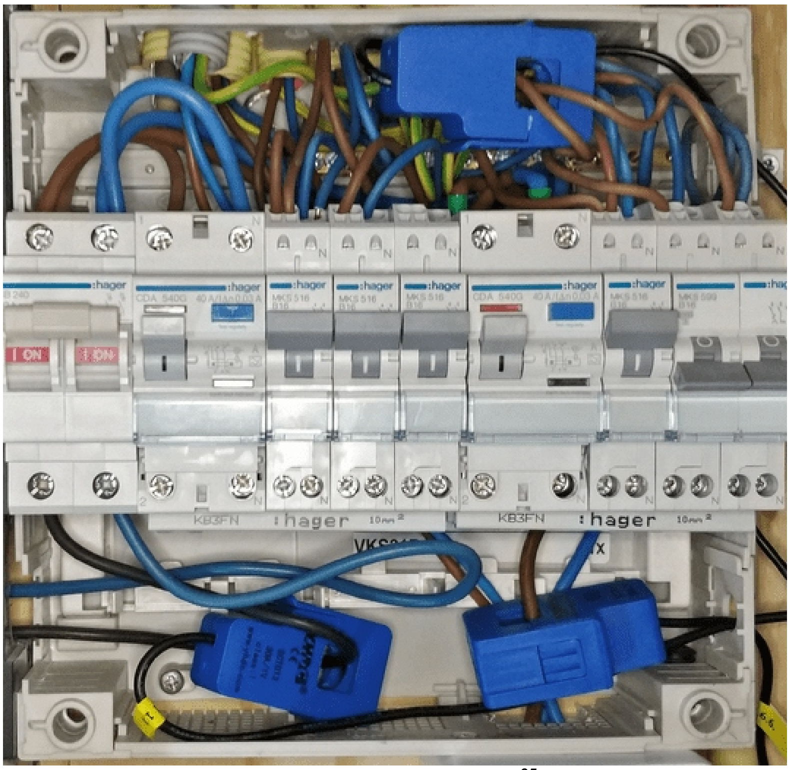


Image 76: CT clamps in a distribution board[35]

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