NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

[illegible]

Graduation Project
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Students: [illegible] (20034096)
Hseyin Ozhan Bozdag(20031390)

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GREENHOUSES PLC SIMULATION

Graduation Project
EE- 400

Students: Zeyad Al kayyali (20034096)
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ABSTRACT

The aim of this project is control the greenhouse by using the programmable logic controller (PLC).

The equipments, which we will use to control the greenhouse, are temperature sensor, humidity sensor and CO_2 sensor. The function of these sensors is taking the readings of temperature, humidity and carbon dioxide. And on the other hand we will use fans and heaters and sprinklers as actuators.

INTRODUCTION

Without controlling system in the greenhouse the owner of the greenhouse must be near to greenhouses to check the conditions and keep it at the wanted level. If the results are not at the wanted levels and according to this conditions he may be has to start the greenhouse actuator manually to keep the greenhouse parameter at the wanted level.

But using PLC control system the sensors takes the values of the parameters and it processes these values in PLC according to program and activates the actuators.

In chapter one

Introduction to PLC; the basic concepts about PLC and some frequently commands used in PLC programming. Then an over view of some kind of sensor.

In chapter two

Greenhouses; types of greenhouses, the main problems which the greenhouse owners face and the solution of these problems.

Finally in chapter three

How to use the PLC for controlling the temperature, humidity, and CO_2 with using the fans, heater and sprinklers.

At the end short explanations about the actuator used in this project.

CHAPTER 1

INTRODUCTION TO PLC

1.1 PLC History

In the late 1960's PLCs were first introduced. The primary reason for designing such a device was eliminating the large cost involved in replacing the complicated relay based machine control systems. Bedford Associates (Bedford, MA) proposed something called a Modular Digital Controller (MODICON) to a major US car manufacturer. Other companies at the time proposed computer based schemes, one of which was based upon the PDP-8. The MODICON 084 brought the world's first PLC into commercial production.

When production requirements changed so did the control system. This becomes very expensive when the change is frequent. Since relays are mechanical devices they also have a limited lifetime which required strict adhesion to maintenance schedules. Troubleshooting was also quite tedious when so many relays are involved. Now picture a machine control panel that included many, possibly hundreds or thousands, of individual relays. The size could be mind boggling. How about the complicated initial wiring of so many individual devices! These relays would be individually wired together in a manner that would yield the desired outcome.

These "new controllers" also had to be easily programmed by maintenance and plant engineers. The lifetime had to be long and programming changes easily performed. They also had to survive the harsh industrial environment. The answers were to use a programming technique most people were already familiar with and replace mechanical parts with solid-state ones.

In the mid70's the dominant PLC technologies were sequencer state-machines and the bit-slice based CPU. The AMD 2901 and 2903 were quite popular in Modicon and A-B PLCs. Conventional microprocessors lacked the power to quickly solve PLC logic in all but the smallest PLCs. As conventional microprocessors evolved, larger and larger PLCs were being based upon them. However, even today some are still based upon the 2903. Modicon has yet to build a faster PLC than their 984A/B/X which was based upon the 2901.

Communications abilities began to appear in approximately 1973. The first such system was Modicon's Modbus. The PLC could now talk to other PLCs and they could be far away from the actual machine they were controlling. They could also now be used to send and receive varying voltages to allow them to enter the analog world. Unfortunately, the lack of standardization coupled with continually changing technology has made PLC communications a nightmare of incompatible protocols and physical networks.

The 80's saw an attempt to standardize communications with General Motor's manufacturing automation protocol (MAP). It was also a time for reducing the size of the PLC and making them software programmable through symbolic programming on personal computers instead of dedicated programming terminals or handheld programmers. Today the world's smallest PLC is about the size of a single control relay!

The 90's have seen a gradual reduction in the introduction of new protocols, and the modernization of the physical layers of some of the more popular protocols that survived the 1980's. The latest standard (IEC 1131-3) has tried to merge PLC programming languages under one international standard. We now have PLCs that are programmable in function block diagrams, instruction lists, C and structured text all at the same time! PC's are also being used to replace PLCs in some applications. The original company who commissioned the MODICON 084 has actually switched to a PC based control system.

Revenue from hardware, software and services for PLCs currently totals an estimated U.S. $ 1.39 billion per year in North America. The worldwide market is expanding, due primarily to falling costs for both hardware and software.

In mid 1980s, a typical medium range PLC with fifteen to twenty functions cost $500. Today $500 will buy a medium range PLC with sixty discrete and analog functions. Furthermore, a unit with 14 I/Os for propotional-integtal-derivative (PID) loops, and two serial ports cost $99. Matched with a $69 four-channel plug-in card, that unit is very cost effective.

With the price reduction and technical advances, applications for PLCs have mushroomed. PLCs are increasingly used to connect and work with other computer and automated systems and components. Use of PLCs has also expanded in safety systems and for redundancy for greater reliability. The growing need for PLC training parallels the expanding market for the devices.

Reasons of Using the PLCs

• Hardwired panels were very time consuming to wire, debug and change.

• GM identified the following requirements for computer controllers to replace hardwired panels.

– Solid-state not mechanical

– Easy to modify input and output devices

– Easily programmed and maintained by plant electricians

– Be able to function in an industrial environment

The First Programmable Logic Controllers (PLCs)

• Introduced in the late 1960's

• Developed to offer the same functionality as the existing relay logic systems

• Programmable, reusable and reliable

– Could withstand a harsh industrial environment

– They had no hard drive, they had battery backup

– Could start in seconds

– Used Ladder Logic for programming

1.2 The function of Programmable Logic Controller

A programmable logic controller (PLC) is a specialized computer used to control machines and process. It uses a programmable memory to store instructions and specific functions that include On/Off control, timing, counting, sequencing, arithmetic, and data handling.

1.2.1 Advantages of PLC Control Systems

• Flexible.

• Faster response time.

• Less and simpler wiring.

• Solid-state - no moving parts.

• Modular design - easy to repair and expand.

• Handles much more complicated systems.

• Sophisticated instruction sets available.

• Allows for diagnostics "easy to troubleshoot".

• Security

• Less expensive.

Eliminates much of the hard wiring that was associated with conventional relay control circuits.

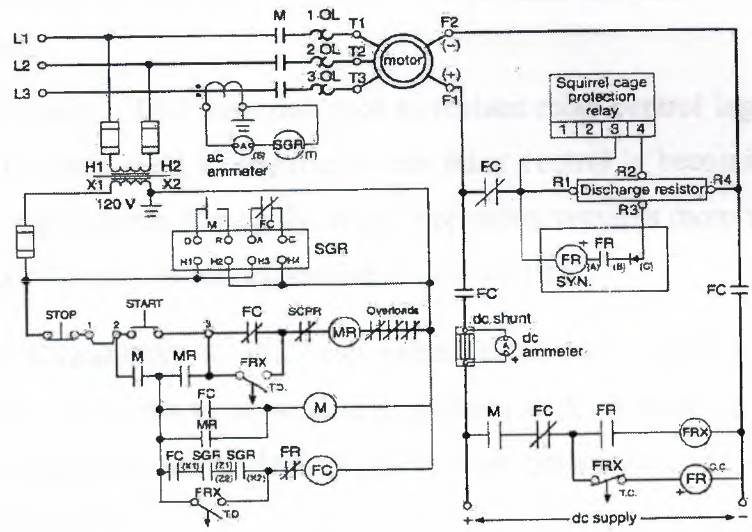


Figure 1.1 Relay Control Circuit

The program takes the place of much of the external wiring that would be required for control of a process.

Increased Reliability: Once a program has been written and tested it can be downloaded to other PLCs.

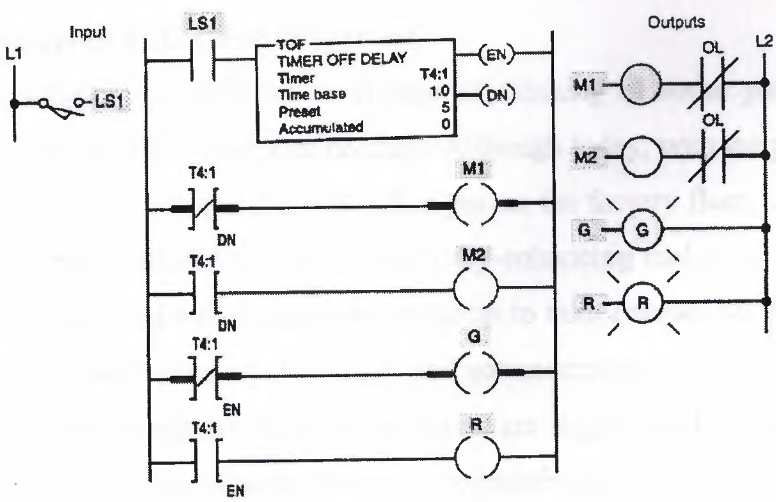


Figure 1.2 Ladder Logic program

Since all the logic is contained in the PLC's memory, there is no chance of making a logic wiring error.

More Flexibility: Original equipment manufacturers (OEMs) can provide system updates for a process by simply sending out a new program. It is easier to create and change a program in a PLC than to wire and rewire a circuit. End-users can modify the program in the field.

Lower Costs: Originally PLCs were designed to replace relay control logic. The cost savings using PLCs have been so significant that relay control is becoming obsolete, except for power applications. Generally, if an application requires more than about 6 control relays, it will usually be less expensive to install a PLC.

Communications Capability: A PLC can communicate with other controllers or computer equipment. They can be networked to perform such functions as: supervisory control, data gathering, monitoring devices and process parameters, and downloading and uploading of programs.

Faster Response Time: PLCs operate in real-time which means that an event taking place in the field will result in an operation or output taking place. Machines that process thousands of items per second and objects that spend only a fraction of a second in front of a sensor require the PLC's quick response capability.

Easier To Troubleshoot: PLCs have resident diagnostic and override functions allowing users to easily trace and correct software and hardware problems.

The control program can be watched in real-time as it executes to find and fix problems.

1.2.2 Disadvantages of PLC Control Systems

• **Newer Technology:** It is difficult to change of thinking of some personnel from ladders and relays to the PLC computer concept. Although today, with the pervasive use of computers not only at home and in the office but on the factory floor, acceptance of the computer as a powerful and reliable productivity-enhancing tool is, if not universal, almost so. Electricians and technicians are lining up to take courses on PLCs because they know doing so contributes to job security and advancement.

• **Fixed Program Applications:** Some applications are single function applications. It does not pay to use PLC that includes multiple programming capabilities if they are not needed.

• **Environmental Consideration:** Certain process environments, such as high heat and vibration, interfere with electronic devices in PLCs, which limit their use.

• **Fail-Safe Operation:** In relay systems, the stop button electrically disconnects the circuit; if the power fails, the system stops. Furthermore, the relay system does not automatically restart when power is restored. This of course can be programmed into the PLC; however, in some PLC programs, you may have to apply an input voltage to cause a device to stop. These systems are not fail-safe. This disadvantage can be overcome by adding safety relays to a PLC system.

• **Fixed Circuit Operation:** If the circuit in operation is never alerted, a fixed control system (such as a mechanical drum) might be less costly than PLC. The PLC is the most effective when periodic changes in operation are made.

1.3 PLC Architecture

An open architecture design allows the system to be connected easily to devices and programs made by other manufacturers.

A closed architecture or proprietary system is one whose design makes it more difficult to connect devices and programs made by other manufacturers.

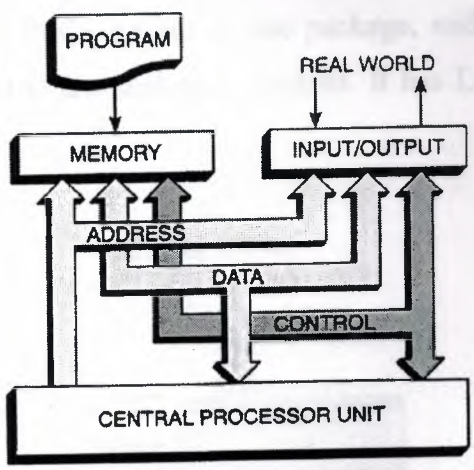


Figure 1.3 The Structure of a PLC is based on the same principles as those employed in computer architecture.

1.4 PLC System

PLC system consists of input module, output module, power supply, CPU, memory and programming device.

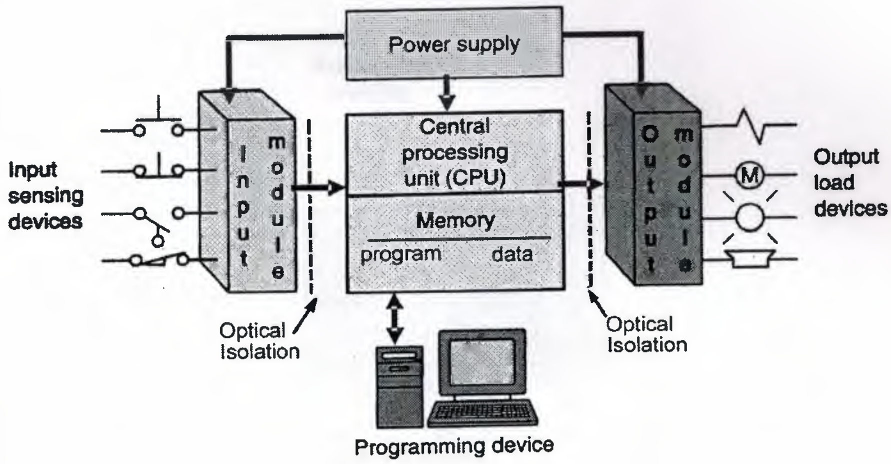


Figure 1.4 PLC System

1.4.1 I/O Configurations

Fixed I/O

Is typical of small PLCs, comes in one package, with no separate removable units. The processor and I/O are packaged together. It has Lower in cost – but lacks flexibility.

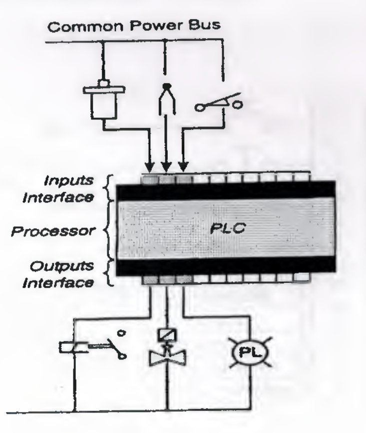


Figure 1.5 Fixed I/O

Modular I/O

Is divided by compartments into which separate modules can be plugged. This feature greatly increases your options and the unit's flexibility. You can choose from all the modules available and mix them in any way you desire.

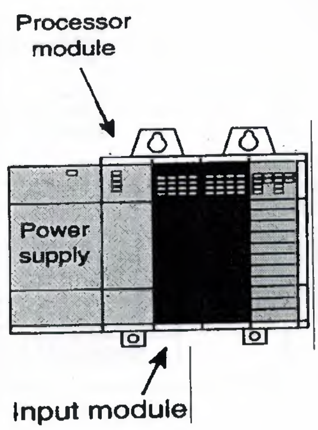


Figure 1.6 Modular I/O

When a module slides into the rack, it makes an electrical connection with a series of contacts - called the backplane. The backplane is located at the rear of the rack.

1.4.2 I/O Section

Input Module

Forms the interface by which input field devices are connected to the controller. The terms field" and "real world" are used to distinguish actual external devices that exist and must be physically wired into the system.

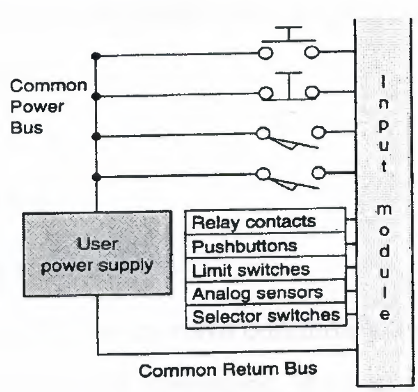


Figure 1.7 Input Field Devices

Output Module

Forms the interface by which output field devices are connected to the controller. PLCs employ an optical isolator which uses light to electrically isolate the internal components from the input and output terminals.

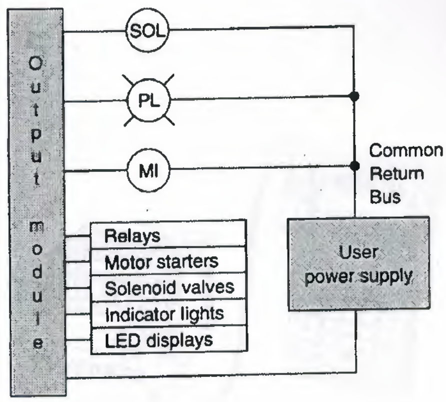


Figure 1.8 Output Field Devices

1.4.3 Power Supply

Supplies DC power to there modules that plug into the rack. In large PLC systems, this power supply does not normally supply power to the field devices. In small and micro PLC systems, the power supply is also used to power field devices.

1.4.4 Central Processing Unit (CPU)

Is the "brain" of the PLC. Consists of a microprocessor for implementing the logic, and controlling the communications among the modules. Designed so the desired circuit can be entered in relay ladder logic form. The processor accepts input data from various sensing devices, executes the stored user program, and sends appropriate output commands to control devices.

1.5 Programming Device

1.5.1 PC with appropriate software

A personal computer (PC) is the most commonly used programming device. The software allows users to create, edit, document, store and troubleshoot programs. The personal computer communicates with the PLC processor via a serial or parallel data communications link.

1.5.2 Hand-held unit with display

Hand-held programming devices are sometimes used to program small PLCs. They are compact, inexpensive, and easy to use, but are not able to display as much logic on screen as a computer monitor. Hand-held units are often used on the factory floor for troubleshooting, modifying programs, and transferring programs to multiple machines.

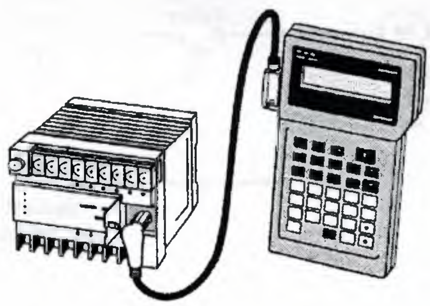


Figure 1.9 Hand-held unit with display

1.6 PLC Mixer Process Control Problem

Mixer motor to automatically stir the liquid in the vat when the temperature and pressure reach preset values. Alternate manual pushbutton control of the motor to be provided. The temperature and pressure sensor switches close their respective contacts when conditions reach their preset values.

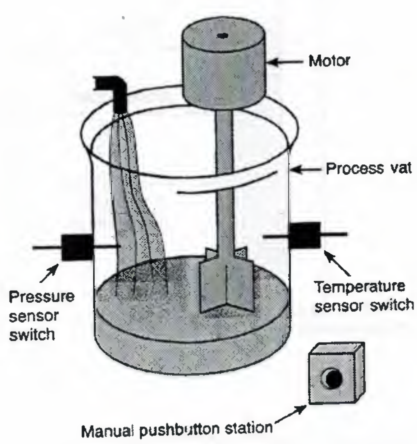


Figure 1.10 Mixer

1.6.1 Process Control Relay Ladder Diagram

Motor starter coil is energized when both the pressure and temperature switches are closed or when the manual pushbutton is pressed.

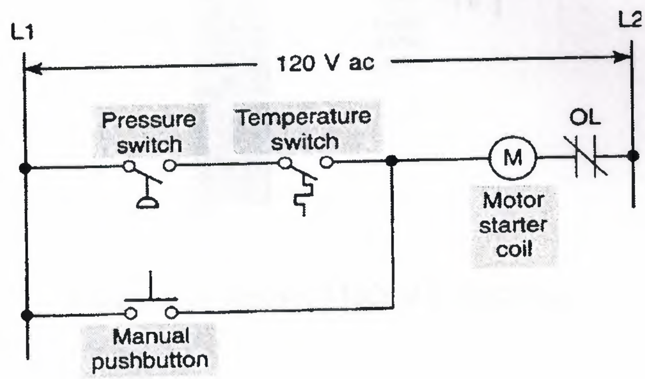


Figure 1.11 Ladder Diagram

1.6.2 PLC Input Module Connections

The same input field devices are used. These devices are wired to the input module according to the manufacturer's labeling scheme.

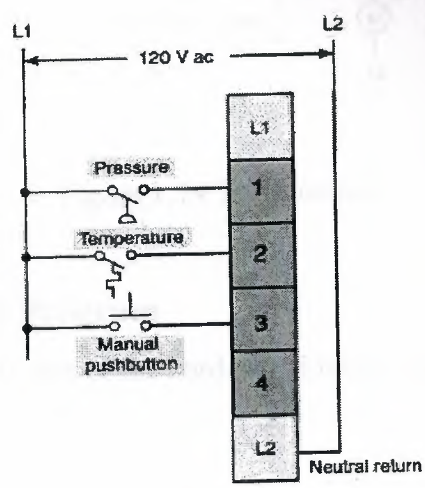


Figure 1.12 Input Module Connections

1.6.3 PLC Output Module Connections

Same output field device is used and wired to the output module.

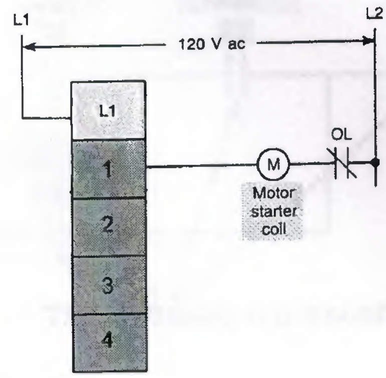


Figure 1.13 Output Module Connections

Triac switches motor ON and OFF in accordance with the control signal from the processor.

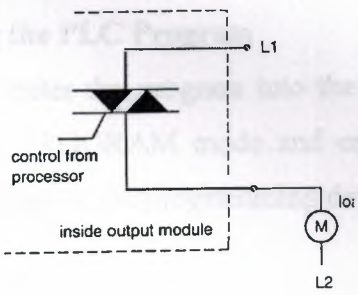


Figure 1.14 Triac switch

1.7 PLC Ladder Logic Program

The format used is similar to that of the hard-wired relay circuit

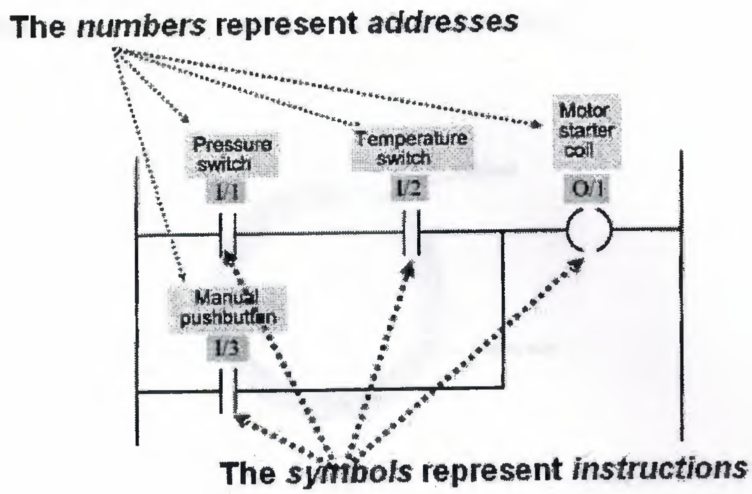


Figure 1.15 Format of Ladder Program

I/O address format will differ, depending on the PLC manufacturer. You give each input and output device an address. This lets the PLC know where they are physically connected.

Entering and Running the PLC Program

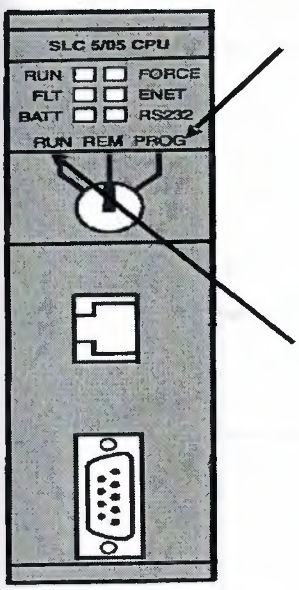


Figure 1.16

To enter the program into the PLC, place the processor in the PROGRAM mode and enter the instructions one-by-one using the programming device.

To operate the program, the controller is placed in the RUN mode, or operating cycle.

PLC Operating Cycle

During each operating cycle, the controller examines the status of input devices, executes the user program, and changes outputs accordingly.

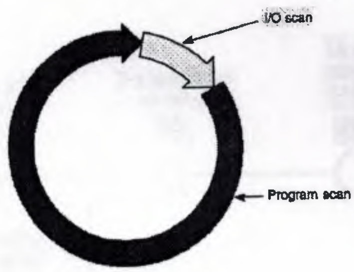


Figure 1.17 PLC Operating Cycle

The completion of one cycle of this sequence is called a scan. The scan time, the time required for one full cycle, provides a measure of the speed of response of the PLC.

1.7.1 Modifying A PLC Program

The change requires that the manual pushbutton control should be permitted to operate at any pressure but not unless the specified temperature setting has been reached.

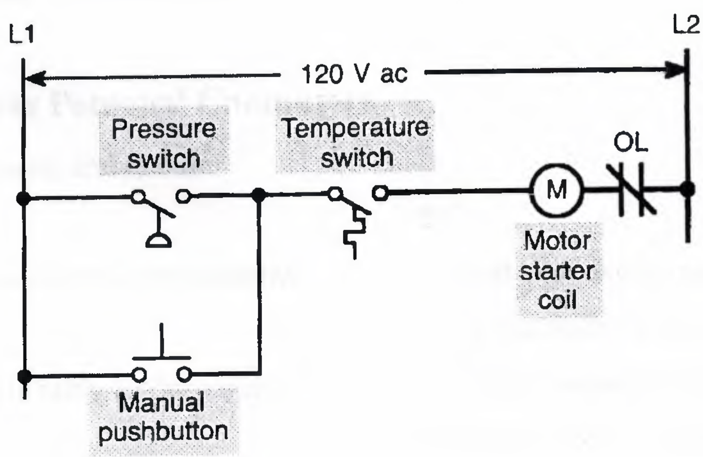


Figure 1.18 Relay ladder diagram for modified process.

If a relay system were used, it would require some rewiring of the system, as shown, to achieve the desired change.

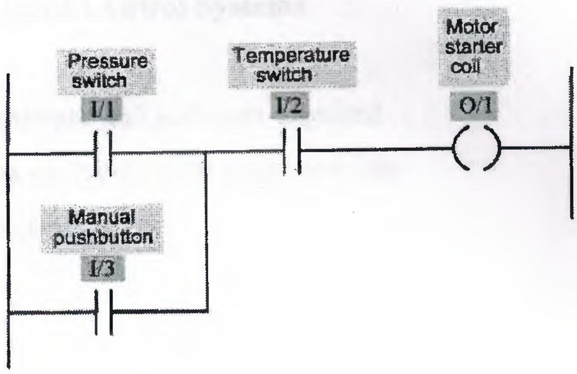


Figure 1.19 PLC ladder logic diagram for modified process.

If a PLC is used, no rewiring is necessary! The inputs and outputs are still the same. All that is required is to change the PLC program.

Each —| |— can be though of as a set of normally open contacts.

The —( )— can be considered to represent a coil that, when energized, will close a set of contacts.

Coil O/1 is energized when contacts I/1 and I/2 are closed or when contact I/2 and I/3 is closed. Either of these conditions provides a continuous path from left to right across the rung that includes the coil.

1.8 PLCs versus Personal Computers

Both have same basic architecture

PLC	PC
- Operates in the industrial environment	- Capable of executing several programs simultaneously, in any order
- Is programmed in relay ladder logic	- Some manufacturers have software and interface cards available so that a PC can do the work of a PLC
- Has no keyboard, CD drive, monitor, or disk	

drive

- Has communications ports, and terminals for input and output devices

Advantages of PC Based Control Systems

- Lower initial cost
- Less proprietary hardware and software required
- Straightforward data exchange with other systems
- Speedy information processing
- Easy customization

1.9 PLC Size Classification

Criteria	- Number of inputs and outputs (I/O count) - Cost - Physical size
Nano PLC	Smallest sized PLC Handles up to 16 I/O points
Micro PLC	Handles up to 32 I/O points
Allen-Bradley SLC-500 Family	Handles up to 960 I/O points
Allen-Bradley PLC-5 Family	Handles several thousand I/O points

1.10 PLC Instruction Set

The instruction set for a particular PLC type lists the different types of instructions supported. An instruction is a command that will cause a PLC to perform a certain predetermined operation.

Typical PLC Instructions

XIC (Examine ON) . . . . Examine a bit for an ON condition

XIO (Examine OFF) . . . . . . Examine a bit for an OFF condition

OTE (Output Energize) . . . . Turn ON a bit (non retentive)

OTL (Output Latch). . . . . . Latch a bit (retentive)

OTU (Output Unlatch). . . . Unlatch a bit (retentive)

TOF (Timer Off-Delay) . . . . Turn an output ON or OFF after its rung has been OFF a preset time interval

TON (Timer On-Delay) . . . . Turn an output ON or OFF after its rung has been ON for a preset time interval

CTD (Count Down) . . . . Use a software counter to count down from a specified value

CTU (Count Up) . . . . Use a software counter to count up to a specified value.

1.11 Sensors

1.11.1 Temperature Sensors

Changes that are commonly used to monitor temperature are the expansion or contraction of solids, liquids or gases, the change in electrical resistance of conductors and semiconductors, thermoelectric e.m.f.s, etc.

Bimetallic strips

This device consists of two different metal strips bonded together. The metals have different coefficients of expansion and when the temperature changes the composite strip bends into a curved strip, with the higher coefficient metal on the outside of the curve. This deformation may be used as a temperature-controlled switch, as in the simple thermostat commonly used with domestic heating systems.

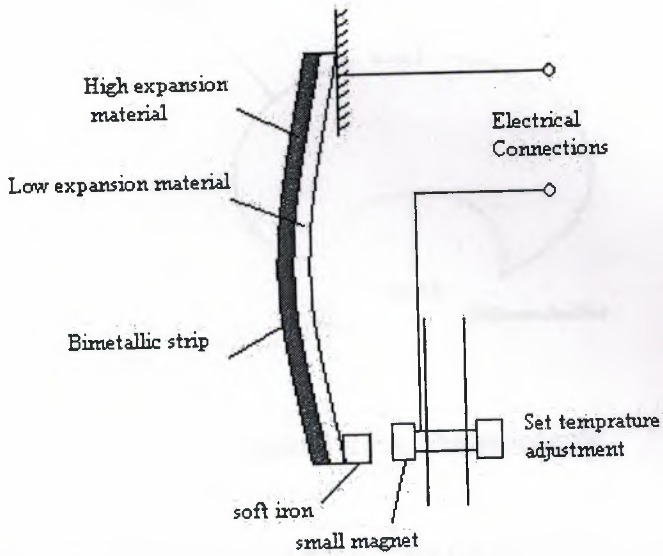


Figure 1.20 Bimetallic Strips

Thermocouples

If two different metals are joined together; a potential difference occurs across the junction. The potential difference depends on the metals used and temperature of the junction. A thermocouple is a complete circuit involving such two junctions. If both junctions are at the same two metals concerned and the temperatures t of both junctions. Usually one junction is held at 0°C and then, to a reasonable extent, the following relationship holds. Temperature there is no net e.m.f. If, however, there is a difference in two junctions there are an e.m.f. The value of this e.m.f. E depends on the

$$E = at + bt^2 \ldots. (1.1)$$

Where a and b are constants for the metals concerned. Figure 1.21 shows how the e.m.f. varies with temperature for a number of commonly used pairs of metals. Standard tables are available for the metals usually used for thermocouples.

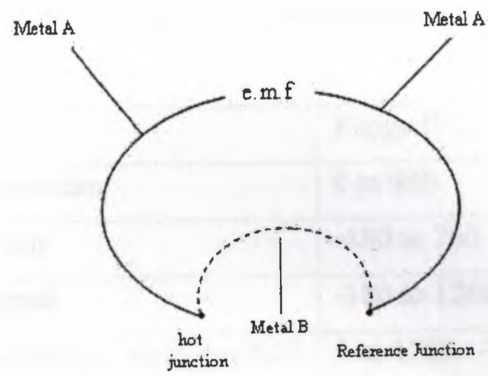


Figure 1.21 A Thermocouple

A thermocouple circuit can have other metals in the circuit and they will have no effect on the thermoelectric e.m.f. provided all their junctions are the same temperature. A thermocouple can be used with the reference junction at a temperature other than 0°C. The standard tables, however, assume a 0°C junction and hence a correction has to be applied before the tables can be used. The correction applied using what is known as the law of intermediate temperatures, namely

$$E_{t,0} = E_{t,J}. + E_{l,0} \dots (1.2)$$

The e.m.f. $E_{t,0}$ at temperature t when the cold junction is at 0°C equals the e.m.f. $E_{t,J}$ at the intermediate temperature I plus the e.m.f. $E_{l,0}$ at temperature I when the cold junction is at 0°C. To maintain one junction of a thermocouple at 0°C, i.e. have it immersed in a mixture of ice and water, s often not convenient. A compensation circuit can however be used to provide an e.m.f. which varies with the temperature of the cold junction in such a way that when it is added to the thermocouple e.m.f. it generates a combined e.m.f. which is the same as would have been generated if the cold junction had been at 0°C.

Commonly used thermocouples are shown in table 1.1 with the temperature ranges over which they are generally used and typical sensitivities.

Table 1.1 Thermocouples

Type	materials	Range (°C)	Sensitivity (μV/°C)
E	Chromel-constantan	0 to 980	63
J	Iron-constantan	-180 to 760	53
K	Chromel-alumel	-180 to 1260	41
R	Platinium-platinium / rhodium %13	0 to 1750	8
T	Copper-constantan	-180 to 370	43

These commonly used thermocouples are given reference letters. For example, the iron-constantan thermocouple is called a type J thermocouple. The base-metal thermocouples, E, J, K and T, are relatively cheap but deteriorate with age. They have accuracies which are typically about ±1 to 3%. Noble-metal thermocouples, e.g. R, are more expensive but are more stable with longer life. They have accuracies f the order of ±1% or better.

1.11.2 Humidity sensor

Of all common environmental parameters, humidity is perhaps the least understood and most difficult to measure. The most common electronic humidity detection methods, although. Highly accurate, are not obvious and tend to be expensive and complex. Accurate humidity measurement is vital to a number of diverse areas, including food processing, paper and lumber production, pollution monitoring and chemical manufacturing. Despite these and other applications, little design oriented material has appeared on circuitry to measure humidity. This is primarily due to the small number of transducers available and a generally accepted notion that they are difficult and expensive to signal condition. Although not as accurate as other methods, the sensor. Described by the response curve (Figure 1.22) is inexpensive and provides a direct readout of relative humidity. The curve reveals a close exponential relationship between the sensors and relative humidity spanning almost 4 decades of resistance. Linearization of this curve may be accomplished by taking the logarithm of the resistance value and utilizing breakpoint approximation techniques to minimize the residual non-linear ties. A further consideration in signal conditioning is that the manufacturer specifies that no significant DC current component may pass through the sensor. This device must be excited with an unbiased AC waveform to preclude detrimental electrochemical migration. In addition, it has a 0.36 RH unit/°C positive temperature coefficient. The sensor is a chemically treated styrene copolymer which has a surface layer whose resistivity varies with relative humidity. Because the humidity sensitive portion of the sensor is at its surface, time response is reasonably rapid and is on the order of seconds.

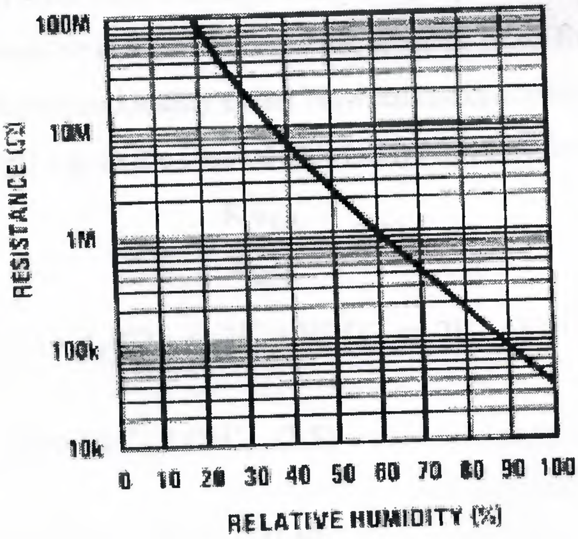


Figure 1.22

A block diagram of the concept chosen to instrument the sensor appears in Figure 1.23. An amplitude stabilized square wave which is symmetrical about zero volts is used to provide a precision alternating current through the sensor, satisfying the requirement for a zero DC component drive. The current through the sensor is fed into a current sensitive (e.g. the input is at virtual ground) logarithmic amplifier, which linearizes sensor response. The output of the logarithmic amplifier is scaled, rectified and filtered to provide a DC Output which represents relative humidity. Residual non-linearity due to the sensors non-logarithmic response below RH = 40% is compensated by breakpoint techniques in this final stage.

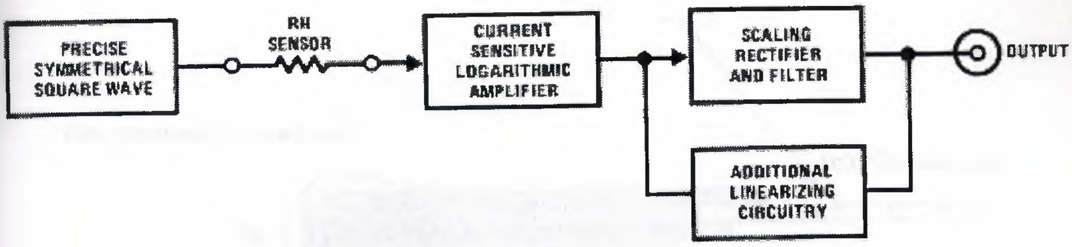


Figure 1.23

1.11.3 Carbon dioxide sensor

Gases that react with water freeing or absorbing a proton in the electrolyte may be detected by a pH sensitive detector element e.g. glass or IrOx. Example gases: CO_2, NH_3, H_2S, etc. A direct proportionality exists between the concentration of the neutral gas and the measured pH e.g. in the case of CO_2 (with $NaHCO_3$ for internal electrolyte)

i.e. $$a_{H^+} = \frac{K\, a_{CO_2}}{a_{HCO^-_3}} \text{....(1.3)}$$

$$CO_2 + H_2O \Leftrightarrow H_2CO^-_3 \Leftrightarrow H^+ + HCO^-_3 \Leftrightarrow 2H^+ + CO^{2-}_2 \text{....(1.4)}$$

$$NH_3 + H_2O \Leftrightarrow NH^+_4 + OH^- \text{....(1.5)}$$

$$H_2S + H_2O \Leftrightarrow HS^- + H_3O^+ \text{....(1.6)}$$

$$E_{cell} = E_{ind} - E_{ref} \text{.... (1.7)}$$

As the indicator is only H^+ sensitive, and the potential of the reference is a constant (because of the constant chloride concentration in the electrolyte), we have

$$E_{cell} = K_1 + 0.059 \log a_{H^+} \text{ (at 25°C)....(1.8)}$$

CO_2 penetrates through the gas permeable membrane and will react with the electrolyte in the agar hydrogel:

$$CO_2 + H_2O = H^+ + HCO_3^- \text{.... (1.9)}$$

$$a_{H^+} = K' P_{CO_2} a_{H_2O} / a_{HCO_3^-} \text{.... (1.10)}$$

As the activities for H_2O and HCO_3^- are constant in the electrolyte, the voltage of the sensor cell should be:

$$E_{cell} = K_2 + 0.059 \log P_{CO_2} \text{.... (1.11)}$$

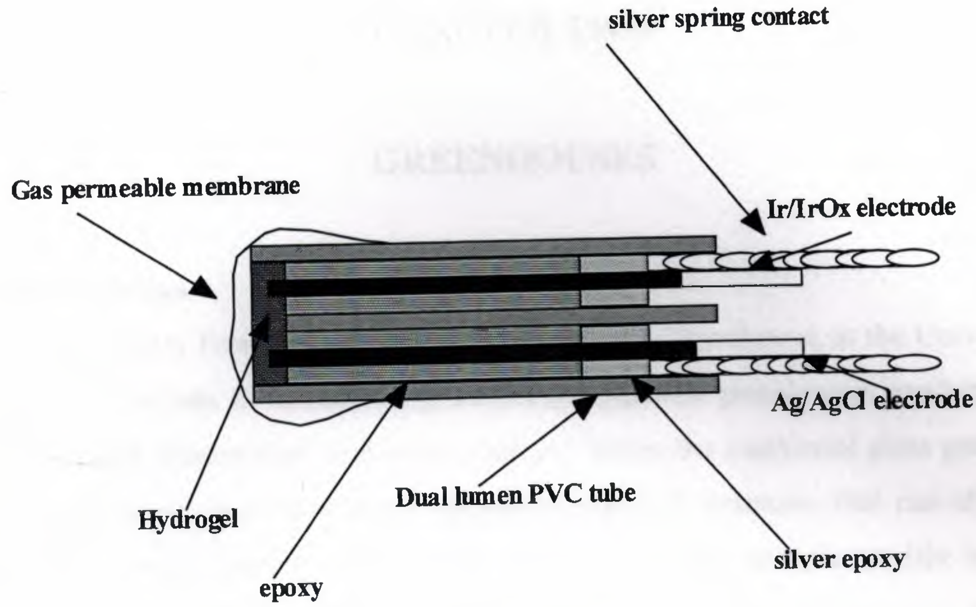


Figure 1.24 CO_2 Sensor

A pH, CO_2 and oxygen electrochemical sensor array for in-vivo blood measurements was made using MEMS techniques.

The pH and CO_2 sensors are potentiometric and the oxygen sensor is amperometric.

The pH sensor is an ISE based on a pH sensitive polymer membrane.

The CO_2 sensor is based on an IrOx pH sensor and Ag/AgCl reference electrode.

CHAPTER TWO

GREENHOUSES

2.1 Introduction

Dr. Emery Emmert, "The Father of the Plastic Greenhouse, at the University of Kentucky in the late 1940s and early 1950s, the types of greenhouses available today are much more diverse than many may realize. While the traditional glass greenhouse is still with us, we now have many alternative types of structures that can effectively extend the growing season. These ranges from very simple greenhouse-like structures (low tunnels) to field greenhouses (high tunnels with or without heat) to the more conventional greenhouses and to greenhouse complexes of 162 m² in size or more.

2.2 Types of Greenhouse Structures

2.2.1 Low tunnels

Low tunnels are basically row covers supported on wire hoops. They are often used in conjunction with black plastic mulch and drip irrigation. The covers are generally in place for only three or four Weeks and then removed. Besides providing an excellent means of extending the growing season, Low tunnels also offer wind protection.

Once hoops are set, the plastic cover is applied with the edges of the plastic secured by burying in the soil. Modifications have been made on this basic design to allow for daytime ventilation when temperatures within the plastic begin to rise to dangerous levels. While cucurbits are more tolerant of high temperatures, ventilation is a must for some crops such as tomato and pepper. One way to provide ventilation is to simply place slits in the plastic to allow the heat to escape. An alternative system involves using two narrower sheets of plastic with a seam at the peak of the hoops. This seam is secured by clothespins, which can be removed to open the tunnel for ventilation. Another method, the double hoop system, makes use of two hoops with the plastic Sandwiched between them. Because the edges of the plastic are not buried, the sides of the tunnel can be Raised and lowered as needed for ventilation.

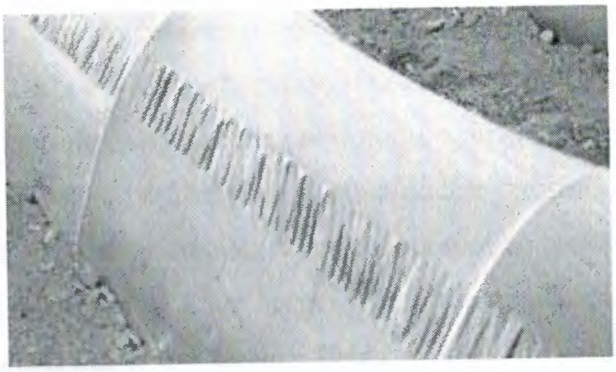


Figure 2.1 Low Tunnel

2.2.2 High tunnels

The field greenhouse of Dr. Emmert's day is now generally called a "high tunnel" by vegetable Producers, an "over wintering Quonset" by nurserymen and a "cold frame" by those in the bedding plant Industry. Regardless, it is a simple, relatively permanent stand-alone greenhouse up to 15 feet wide and 8 to 9 Feet high, with or without heat. It can be placed over ground beds so you are essentially gardening in a Greenhouse.

Vegetables, small fruits and flowers can be grown using high tunnels. High tunnels generally have Quonset Shaped frames covered with a single layer of greenhouse-grade polyethylene. The frames can be constructed of metal pipe or wood. There can be problems in attaching the plastic to the wood frame and in this regard metal pipe is easier to work with. Research is being conducted on the use of PVC frames; however, additional work still needs to be done before recommendations can be made. The plastic cover is put into place on the first of February after which seed is sown. The cover can be removed after the last frost-free date in mid-May and then replaced October 1. Soon after thanksgiving, the cover should be removed to prevent damage from snow build-up.

High tunnels are ventilated by manually rolling up the sides each morning and rolling them back down in the evening. Pennsylvania State University has developed a design in which the end walls are hinged and a small tractor or tillers can be driven in. New Hampshire's system uses plastic mulch to cover the entire soil surface under the tunnel, making tilling unnecessary. High tunnels do not have any external connections, except for the water supply for trickle irrigation. While they do not have a permanent heating system, some growers choose to have a portable heater available for unexpected drops in temperature. While lacking the precision of the environmentally controlled greenhouse, high tunnels do moderate the environment sufficiently to improve crop growth, yields, and crop quality. The yield is often double the amount that could be produced in the field without the tunnel. A combination of an earlier planting date, along with the more rapid ripening that occurs within the tunnel, can result in mature tomatoes as much as one month earlier than field tomatoes. In addition, when vented properly, serious foliar and fruit diseases are often fewer since plant surfaces remain dry while in the protective environment of the high tunnel.

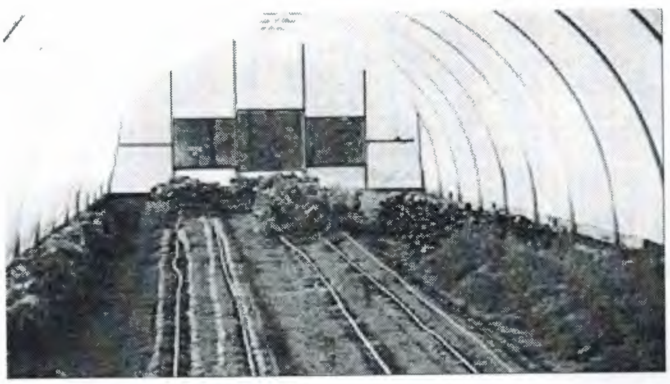


Figure 2.2 High Tunnel Greenhouse

2.2.3 Conventional greenhouses

Conventional greenhouses may be 20 feet or more in width and 100 feet or more in length with frames of aluminum, galvanized steel or wood. Glazings or coverings are typically glass, rigid clear plastic, or polyethylene. If only a single greenhouse is required, it can be built as a stand-alone unit. However, when multiple houses are needed (either initially or as part of a future expansion) the greenhouses should be gutter-connected for more efficient use. The greatest advantage to a conventional greenhouse is the ability to completely control the environment to suit the plants being produced. Today this is called controlled-environment agriculture, or CEA. These greenhouses have heat, mechanical ventilation and an irrigation system that can also be used to distribute liquid fertilizer. A monitoring device is essential for determining whether the greenhouse conditions are within the proper range the crop requires.

Greenhouses may also have benches and various other machinery and hand equipment to aid in the production and handling of the crop. Greenhouse conditions that favor plant growth also favor the rapid build-up and spread of insects and diseases. Prevention and careful monitoring are the keys to insect and disease control. Water aeration in the irrigation system can help to reduce water molds. Insect screening on the sidewalls may be necessary for some crops if sidewall ventilation is used. Pesticides must be applied properly and legally. Weed control under benches and around the greenhouse will also help reduce insect pests and disease problems; however, herbicides are not applied in greenhouses.

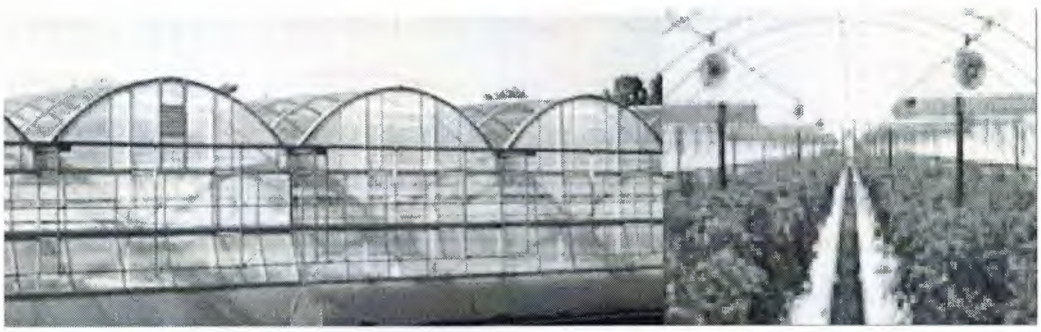


Figure 2.3 Conventional Greenhouse

2.2 Economic Considerations

Crop production in a conventional greenhouse can be a highly profitable venture. However, it is also a high risk business with significant start-up costs, as well as demanding labor and management. Initial investments include greenhouse construction, production system costs and equipment. The cost of a production ready greenhouse, excluding land costs, can run between \$8 and \$30 per square foot.
Low tunnels and high tunnels are relatively inexpensive ways to extend the growing season, requiring little capital investments. Excluding labor, the approximate cost of a low tunnel is \$0.25 per square foot, with high tunnels costing \$1.30 per square foot. Because of their simple design, these structures are not difficult to construct and manage. Tunnels are not automated in any way, so they will require daily attention and labor to ensure proper ventilation. Both types of tunnels could also require monitoring During heavy storms.

2.2.1.1 Type Of Heat Losses

Conduction

Heat is conducted either through a substance or between objects by direct physical contact. The Rate of conduction between two objects depends on the area, path length, temperature Difference and physical properties of the substance(s) (such as density). Heat transfer by Conduction is most easily reduced by replacing a material that conducts heat rapidly with a poor thermal conductor (insulator) or by placing an insulator in the heat flow path. An example of this would be replacing the metal handle of a kitchen pan with a wooden handle or insulating the metal handle by covering it with wood. Air is a very poor heat conductor and therefore a good heat insulator.

Convection

Convection heat transfer is the physical movement of a warm gas or liquid to a colder location. Heat losses by convection inside the greenhouse occur through ventilation and infiltration (fans and air leaks). Heat transfer by convection includes not only the movement of air but also the movement of water vapor. When water in the greenhouse evaporates, it absorbs energy. When water vapor condenses back to a liquid, it releases energy. So when water vapor condenses on the surface of an object, it releases energy to the outside environment.

Radiation

Radiation heat transfer occurs between two bodies without direct contact or the need for a medium such as air. Like light, heat radiation follows a straight line and is either reflected, transmitted or absorbed upon striking an object. Radiant energy must be absorbed to be converted to heat. All objects release heat in all directions in the form of radiant energy. The rate of radiation heat transfer varies with the area of an object, and temperature and surface characteristics of the two bodies involved. Radiant heat losses from an object can be reduced by surrounding the object with a highly reflective, opaque barrier. Such a barrier

(1) Reflects the radiant energy back to its source.

(2) Absorbs very little radiation so it does not heat up and re-radiate energy to outside objects.

2.2 Greenhouse specific requirement

Greenhouses should provide a controlled environment for plant production with sufficient Sunlight, temperature and humidity. Greenhouses need exposure to maximum light, particularly in the morning hours. Consider the location of existing trees and buildings when choosing your Greenhouse site. Water, fuel and electricity make environmental controls possible that are Essential for favorable results. For this reason, use reliable heating, cooling and ventilation. Warning devices might be desirable for use in case of power failure or in case of extreme Temperatures. The house temperature requirements depend upon which plants are to be grown. Most plants require day temperatures of 70 to 80 degrees F, with night temperatures Somewhat Lower. Relative humidity may also require some control, depending on the plants cultured.

Some plants grow best in cool greenhouses with night temperatures of 50 degrees F after they are transplanted from the seeding tray. These plants include azalea, daisy, carnation, aster, beet, Calendula, Camellia, Carrot, Cineraria, Cyclamen, Cymbidium orchid, Lettuce, Pansy, Parsley, Primrose, Radish, Snapdragon, Sweet pea and many bedding plants. Some plants grow best in Warm greenhouses with night temperatures of 65 degrees F. These plants include rose, tomato, poinsettia, lily, hyacinth, Cattleya Orchid, Gloxinia, Geranium, Gardenia, Daffodil, chrysanthemum, coleus, Christmas cactus, calla, caladium, Begonia, African violet, amaryllis and tulip. Tropical plants usually grow best in high humidity with night temperatures of 70 Degrees F.

2.2.1 Greenhouse Heating Requirements

A good heating system is one of the most important steps to successful plant production. Any heating system that provides uniform temperature control without releasing material harmful to the plants is acceptable. Suitable energy sources include natural gas, LP gas, fuel oil, wood and electricity. The cost and availability of these sources will vary somewhat from one area to another. Convenience, investment and operating costs are all further considerations. Savings in labor could justify a more expensive heating system with automatic controls. Greenhouse heater requirements depend upon the amount of heat loss from the structure. Heat loss from a greenhouse usually occurs by all three modes of heat transfer: conduction, convection and radiation. Usually many types of heat exchange occur simultaneously. The heat demand for a greenhouse is normally calculated by combining all three losses as a coefficient in a heat loss equation.

(3) Prevents objects from "seeing" each other, a necessary element for radiant energy exchange to occur.

2.2.1.2 Factors Affecting Heat Loss

Heat loss by air infiltration depends on the age, condition and type of greenhouse. Older greenhouses or those in poor condition generally have cracks around doors or holes in covering material through which large amounts of cold air may enter. Greenhouses covered with large sheets of glazing materials, large sheets of fiberglass or a single or double layer of rigid or flexible plastic have less infiltration (Figure 2.4). The greenhouse ventilation system also has a large effect on infiltration. Inlet and outlet fan shutters often allow a large air exchange if they do not close tightly due to poor design, dirt, damage or lack of lubrication. Window vents seal better than inlet shutters, but even they require maintenance to ensure a tight seal when closed. Solar radiation enters a greenhouse and is absorbed by plants, soil and greenhouse fixtures. The warm objects then re-radiate this energy outward. The amount of radiant heat loss depends on the type of glazing, ambient temperature and amount of cloud cover. Rigid plastic and glass materials exhibit the "greenhouse effect" because they allow less than 4 percent of the thermal radiation to pass back through to the outside.

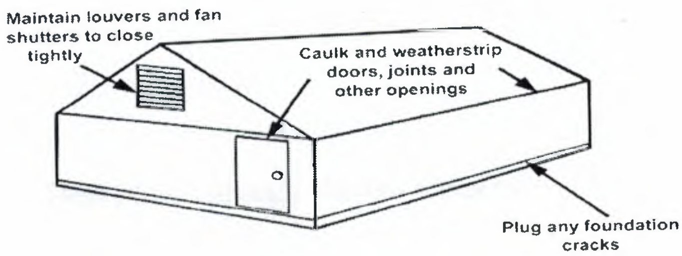


Figure 2.4 Energy losses due to infiltration

2.2.1.3 Heat Loss Calculations

Heat loss by conduction may be estimated with the following equation:

$$Q = A\ (Ti - To)/R \ldots (2.1)$$

Where:

Q = Heat loss, BTU/hr

A = Area of greenhouse surface, sq ft

R = Resistance to heat flow (a characteristic of the material)

(Ti-To) = Air temperature differences between inside and outside.

Table 2.1 lists different materials commonly used in greenhouse construction and their Associated R values.

Table 1 also lists overall R values for various construction assemblies. Note that high R values indicate less heat flow. Building materials that absorb moisture will conduct heat once they are wet. Use vapor barriers to protect materials that are permeable to water vapor. Heat is also lost to the ground underneath and beside a greenhouse. The perimeter heat loss may be added to other losses using Table 1 and the equation:

$$Q = PL\ (Ti - To) \ldots (2.2)$$

P = Perimeter heat loss coefficient, BTU/ft °F hr

L = Distance around perimeter

Table 2.1. Heat Flow Through Various Construction Materials and Assemblies.

Materials	R-Value
Glass Fiber Board 1”	4.0
Expanded polystyrene, 1” cut surfaces	4.0
Expanded polystyrene, 1” smooth skin surfaces	5.0
Expanded polystyrene, molded beads, 1”	3.6
Expanded polyurethane, 1”	6.2
Vermiculite, 1”	2.2
Glass fiber blanket, 3-3,5”	11.0
Glass fiber blanket, 5.0-6,5”	19.0
Wall materials	
Concentrate Block 8”	2.00*
Plywood, ½”	1.43*

Concentrate Block or plywood, plus 1" foamed urethane	7.69*
Or plus 1" polystyrene	5.0*
Greenhouse with thin thermal curtains	1.42-3.33*
Construction Assemblies	
Material	**Overall R-Value**
Roof and wall coverings	
Glass, single layer	0.91"
Glass, double layer, ¼" space	2.00*
Polyethylene or other film, single layer	0.83*
Polyethylene or other film, double layer separated	1.43*
Polyethylene film, double layer, separated, over glass	2.00*
Fiberglass reinforced pane	0.83*
Double acrylic or polycarbonate	2.00*
Perimeter	**Btu/linear ft °F hr**
Uninsulated	0.8
insulated	0.4

* includes effects of surface coefficients.

Add infiltration heat losses to the conduction heat losses. The equation for infiltration heat transfer follows:

$$Q = 0.02\ V\ C\ (Ti - To) \ldots\ (2.3)$$

V = Greenhouse volume, cu ft.

C = Number of air exchanges per hour.

Table 2.2 lists estimates of air exchanges through types of greenhouses. The number of air exchanges per hour will vary depending on the type and condition of the greenhouse and the amount of wind.

Table 2.2 Natural Air Exchanges for Greenhouses

Construction system	Air exchanges per hour[1]
New construction, glass or fiberglass	0.75 to 1
New construction, double layer plastic film	0.5 to 1
Old construction glass, good maintenance	1 to 2
Old construction glass, poor condition	2 to 4

[1]Low wind or protection from wind reduces the air exchange rate.

2.2.2 Ventilation and Cooling

Ventilation reduces inside temperature during sunny days and supplies carbon dioxide, which is vital to the plants' photosynthesis. Another advantage of ventilation is to remove warm, moist air and replace it with Drier air. High humidity is objectionable since it causes moisture condensation on cool surfaces and tends to increase the occurrence of diseases. Some glass houses are ventilated by manually operated ventilators in the roof. This method is usually not satisfactory for ventilating plastic covered houses due to the rapid temperature fluctuations possible. Ventilating fans are highly recommended in Georgia. Winter ventilation should be designed to prevent cold drafts on plants. This has been a problem with some systems using shutters at one end of a house and an exhaust fan at the other. The problem can be minimized by placing the intake high in the gable and using baffles to deflect the incoming air.

Draft-free winter ventilation can be provided by using the convection tube system, consisting of exhaust fans and fresh air inlets located in the gable and end wall. This is connected to a thin plastic tube extending the length of the greenhouse. The tube is suspended on a wire near the ridge and has holes along its entire length. The fans can be thermostatically controlled. Fan operation produces a slight air pressure drop inside the greenhouse, causing fresh air to flow into the inlet and inflate the tube, which discharges air into the house through the holes in the tube. The holes emit "jets" of air that should project horizontally to provide proper distribution and mixing with warm air before reaching the plants. The thermostat stops the fans when the desired temperature is reached; the tube collapses and ventilation stops. In a tightly constructed greenhouse, it makes little difference where fans are located in convection tube ventilation since the air distribution is determined by the tubes. Less fan capacity is usually required for the convection tube system than for any other winter ventilation system. Additional air is necessary as the outdoor temperature rises to the point where full capacity of the tube is reached. The outside air is usually warm enough by this time to be admitted through doors or other openings at plant level. Fans may be added or possibly combined with a cooling pad for use in evaporative cooling. In fact, air may be pulled through the pad with or without water in the pad. In warm periods, enough air needs to be pulled from the house to provide a complete air exchange every 60 seconds. Control fans by a thermostat or humidistat to provide proper temperature and humidity. Greenhouses equipped with an evaporative cooling pad system having three fans or fewer should have one fan with a two-speed motor to prevent excessive temperature fluctuations and fan cycling. Select all fans to operate against a slight pressure (c inch static water pressure). Fans not rated against slight pressure usually move only 60 to 70 percent of the rated air flow when installed in greenhouses. It is recommended that only fans that have been tested and their performance verified by an independent testing lab, such as AMCA, be used, since that is the only assurance that the design ventilation rate is being achieved.

2.2.2.1 Exhaust Fans in End Wall

Fans in the end wall (Figure 2.5) are the most common method of forced ventilation. The air enters through the motorized shutter (winter) and is pulled through the greenhouse by the exhaust fans. The exhaust fans should be able to move small air volumes without drafts (winter) and yet provide enough fan capacity for an air exchange within the house each minute during summer. One air exchange per minute (without evaporative cooling) should keep the temperature about 8 degrees F higher than outside temperatures. One-half of this air volume will produce about a 15-degree F temperature rise, while two air exchanges per minute will cause a temperature rise of about 5 degrees F. Ideally, the length of the house should not exceed 125 feet using this method. Houses up to 250 feet long, however, have been satisfactorily ventilated using this method. Temperature variations are greater in longer houses, so higher ventilation rates are desirable. No air must be allowed to enter the house at the sides or at the fan end. Glazing in glass houses must be well set and the houses in good repair to prevent significant quantities of air leaking into the house. If cooling pads are used during summer, disconnect the motorized Shutter and close it to prevent hot air from entering through the shutter and by passing the Cooling pads. You can connect a perforated plastic tube to the same inlet shutter to provide each end wall is good air distribution for cold weather ventilation. The same principle applies for multiple ridge houses, provided so equipped. One two-speed fan is usually used in small hobby Houses. The total inlet opening in the end wall for summer ventilation (shutter and evaporative pad vent) should provide about 1.5 square feet per 1,000 cubic feet per minute of air moving through the operating fans. The motorized shutter and one or two fans might be connected on one thermostat while the remaining fans are connected to a different thermostat, with air being supplied to these fans through the vent panel containing the evaporative pad.

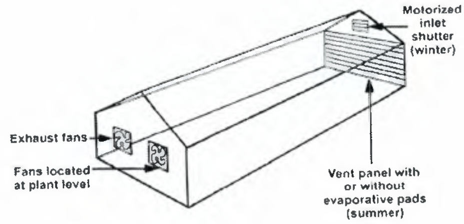


Figure 2.5 Fans in end walls

2.2.2.2 Pressure Fans in End Walls

Ventilation for greenhouses that are 100 feet or shorter can be accomplished by mounting pressure fans, which blow air into the house, high in the end walls. See (Figure 2.6). The fans in the end wall are usually two-speed and controlled by separate thermostats. To avoid high velocity air striking plants, a baffle is placed in front of the fans to direct the air in the direction desired. The fans should have a protective hood to prevent rain from being blown into the house. One pressurized system where evaporative cooling is possible is shown in (Figure 2.7) this system places the pressure fans in the side wall. The pressurized system with fans in the side wall does not work well when the foliage is dense and lots of tall, growing plants are present. Notice the air outlet and inlet are on the same side of the house in this case, with a box enclosure around the fan where cooling pads are installed.

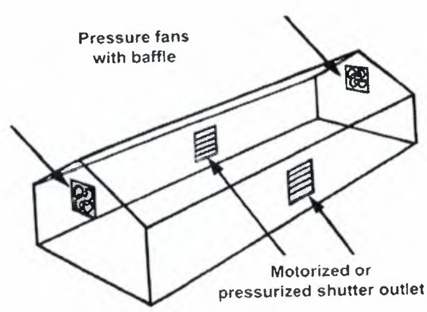


Figure 2.6 Pressure fans mounted high in the end walls.

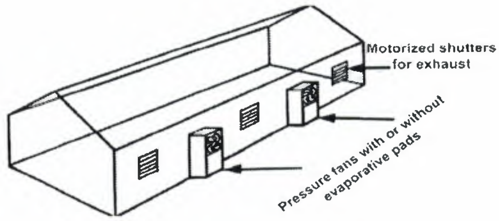


Figure 2.7 Pressure fans mounted in the sidewalls.

2.2.2.3 Evaporative Cooling

The heat absorbed on a dark surface perpendicular to the sun's rays can be as high as 300 BTU/HR per square foot of surface. So it would be possible, theoretically, for a greenhouse to absorb 300 BTUs per hour for each square foot of floor area. This excessive energy leads to heat buildup and, on warm days, can cause plants to wilt. Excessive heat buildup can often be prevented with shading materials such as roll-up screens of Wood, aluminum or vinyl plastic as well as paint-on materials (shading compounds). Roll-up Screens, which work well in hobby houses, are available with pulleys and rot-resistant nylon Ropes. These screen can be adjusted from outside as temperature varies. Radiation can be reduced by 50 percent with this method, which should reduce temperature rise proportionally if Ventilation rate remains constant. Shading also reduces light striking the plants, which may Limit their growth rate since light is essential to photosynthesis. This is a trade-off that is sometimes necessary to reduce temperatures. If summer temperatures exceed those considered Acceptable and cannot be corrected with reasonable ventilation rates and shading, the only alternative is evaporative cooling. A fan and pad system using evaporative cooling eliminates Excess heat and adds humidity. This reduces plant moisture losses and, therefore, reduces plant wilting. Temperature is lowered, humidity is increased and watering needs are reduced. An evaporative cooling system moves air through a screen or spray of water in such a Manner that evaporation of water occurs. About 1,000 BTUs of heat are required to change 1 pound of water from liquid to vapor. If the heat for evaporation comes from the air, the air is cooled. Evaporation is greater when the air entering the system is dry; that is, when the relative humidity is low, allowing the air to evaporate a lot of water. The water holding ability of air is expressed in terms of relative humidity. A relative humidity of 50percent, for example, means the air is holding one-half of the maximum water that the air could hold if saturated at a given temperature. Theoretically air can be cooled evaporative until it reaches 100 percent relative humidity. Practically, a good evaporative cooler can reach about 85 percent of this temperature drop. The cooling effect for 85 percent efficient evaporative coolers is shown in Table 2.3. Evaporative coolers are more effective when the humidity is low (Table 2.3). Fortunately, relative humidities are usually low during the warmest periods of the day. Solar heat entering the house offsets some of the cooling effect. A well-designed ventilation system providing one air volume change per minute is essential for a good evaporative cooling system. A solar heat gain of 8-10 degrees F can be expected using one air change per minute. If the outside air were 90 degrees F and relative humidity were 70 percent, the resulting temperature within the house would be about 93 degrees F (83 degrees F from Table 2.3 plus 10 degrees F).

Table 2.3 Cooling Capacity of 85 Percent Efficient Evaporative Coolers

Relative Humidity

Outside Air	At 30%	At 50%	At 70%	At 90%
Outside air temperature °F	**Cooled air temperature °F**			
100	79	86	91	96
90	70	77	83	87
80	63	69	74	77
70	54	60	64	68

If a cooling efficiency of 85 percent is to be realized, at least 1 square foot of pad area (aspen fiber) mounted vertically should be provided for each 150 CFM of air circulated by the fans. Many pad materials have been used successfully, provided a complete water film does not form and block air movement through the wet pad. Table 2.4 gives recommended air flow through various pad type materials.

Table 2.4 Recommended Airflow Rate through Various Pad Materials.

Pad type	Airflow Rate through Pad (CFM/ft^2)
Aspen fiber mounted vertically (2-4 in. thick)	150
Aspen fiber mounted horizontally (2-4 in. thick)	200
Corrugated cellulose (4 in. thick)	250
Corrugated cellulose (6 in. thick)	350

Aspen pads are usually confined in a welded wire mesh. A pipe with closely spaced holes allows water run down a sheet metal spreader onto the pads (Figure 2.8). The flow rate of the water supplying header pipe is listed in Table 6. Water than does not evaporate in the air stream is caught in the gutter and returned to a reservoir for recycling. The reservoir should have the capacity to hold the water returning from the pad when the system is turned off. Table 2.5 shows recommended reservoir capacity for different type pads.

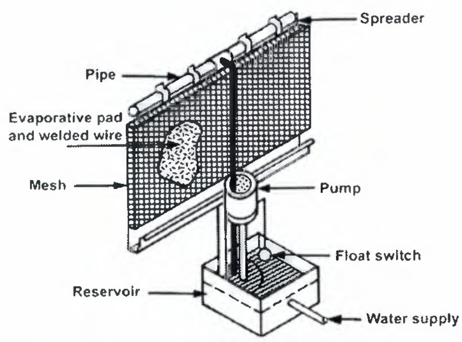


Figure 2.8 Typical evaporative cooling system.

Table 2.5 Recommended Water Flow Rate and Reservoir Capacity for Vertically Mounted Cooling Pad Materials.

Pad type	Min. flowrate per length of pad (gpm/ft)	Min. reservoir capacity per unit pad area (Gal/ft^2)
Aspen fiber (2-4 inches)	0.3	0.5
Corrugated cellulose	0.5	0.8
Corrugated cellulose	0.8	1.0

A cover of some sort is needed to prevent air flow through the pads during cold weather. These can be manually operated or automated. Float control easily controls water supply. It is desirable to use an algaecide in the circulating water to prevent algae growth on the pads. You must, therefore, prevent rain water from entering the evaporative cooling water, causing dilution of the chemical mixture. Evaporative pads in an endue on the suction side of fans that discharge air into houses (pressure fans) have not worked well, primarily due to the distribution of the cooled air. The same is true of package unit evaporative coolers where poor air distribution is concerned. These units can handle air volumes of 2,000 to 20,000 CFM. The problem with them is the difficulty providing uniform cooled air distribution. The closer the units are spaced along the walls, the better the air distribution will be. Package coolers have been used in small houses, and in houses with good air distribution, with considerable success. The pressurized system forces air, which must displace air within the house, into the greenhouse. Vents must be provided for air circulation.

2.2.2.4 Natural Ventilation

Some greenhouses can be ventilated using side and ridge vents, which run the full length of the house and can be opened as needed to provide the desired temperature. This method uses thermal gradients, creating circulation due to warm air rising. Houses with only side vents depend upon wind pressure for ventilation and are usually not satisfactory. The warm air must be allowed to rise through the ridge vent while cooler air enters along the sides. The vent size is important. Ridge vents should be about one fourth the floor area and the side vents about the same size. The roof vents should open above the horizontal position to provide about a 60-degree angle to the roof. Most of these vents are manually operated.

2.2.3 Humidity

2.2.3.1 What is Humidity?

Humidity is an expression of the amount of water vapour in air. It is an invisible gas that varies between 1 - 4% of our atmosphere by volume (see Figure 2.9). Fogs, mists, and other tiny water droplets are not water vapour.

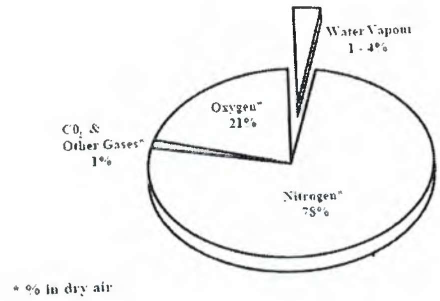


Figure 2.9

The maximum amount of water vapour in any given air sample is dependent on the temperature and to a lesser extent the air pressure (See Figure 2.10). The actual amount of water vapour present is also determined by the availability of free water to evaporate. Water vapour will always move from an area of high concentration (such as inside the leaf cavities) to an area of lower concentration (the greenhouse air). This is the principle behind evaporative transpiration.

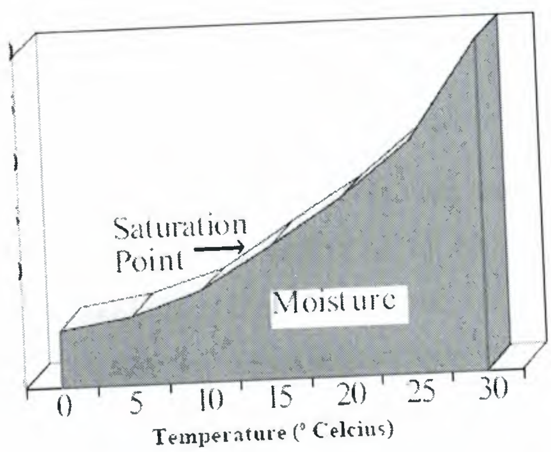


Figure 2.10 the maximum moisture content of air increases as temperatures increases.

Humidity can be the most difficult environmental factor to control i greenhouses. Maintaining set points and correcting for too little or too much humidit can be a challenge for even the most sophisticated monitoring and control equipmen Humidity levels fluctuate with changes in air temperature, and plants are constantl adding water to the air through transpiration. Although automated controls have added higher level of precision to the art of sensing and correcting humidity levels, it is st important to have a good understanding of the dynamics of atmospheric water vapou

There is a natural tendency with sophisticated equipment to just 'set it and forget it'. However, lost yields, plant stress, disease outbreaks, and wasted energy are still as possible as ever unless we realize the limitations of our equipment and the implications of environmental control decisions.

2.2.3.2 Humidity Control Algorithm in the Greenhouse

Probably the last big challenge in the greenhouse automated environment control scene is that involving the control of atmospheric water vapour. Variously termed relative humidity, aerial moisture, vapor pressure or vapor pressure deficit, this variable in the environment of today's highly technical and computer-automated greenhouse plant production system has, until very recently, escaped the close scrutiny afforded temperature and light. This apparent indifference to a rather important environmental influence on plant production and quality was largely the result of inadequate technology in controlling humidity in the greenhouse.

2.2.3.3 What is vapour pressure deficit?

Relative humidity is still the most commonly used measurement for greenhouse control, even though it is not a perfect indication of what the plants 'feel'. Plants respond to the difference between humidity levels at the leaf stomata and the humidity levels of the surrounding air. At the same relative humidity levels, but at different temperatures, the transpiration demand for water from the leaves may be double (See Figure 2.11.) Therefore, another kind of measurement, called the Vapour Pressure Deficit is often used to measure plant/air moisture relationships. Some environmental control companies now offer VPD measurements as a part of their humidity management programs. Tables 2.6 & 2.7 outline vapour pressure deficits (the difference between saturated air and air at various relative humidities). Although different crops vary in their response to humidity levels, a VPD range of 8 - 10 mb has been suggested as an optimum range. VPD can be used for both dehumidifying and humidifying, but it is particularly useful for humidifying.

2.2.3.4 Role of Humidity

The main plant mechanism for coping with humidity is the adjustment of the leaf stomata. Stomata open and close in response to vapour pressure deficit, opening wider as humidity increases. 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 CO_2, thereby affecting photosynthesis

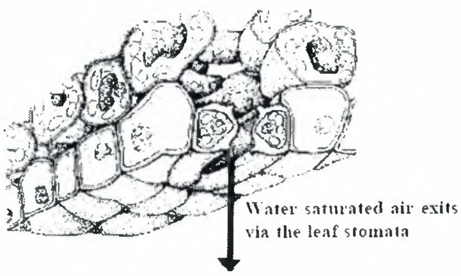


Figure 2.12 The difference in the amount of water vapour in the leaf (always assumed to be saturated or 100% RH) and the outside air is the VPD (Vapour Pressure Deficit). The higher the VPD, the greater the evaporation rate.

• **Transpiration**: Plants can control their rate of water loss. Because the leaf stomata have an ability to limit transpiration rates, a doubling of the moisture deficit may result in only a 15% increase in the transpiration rate. However, when humidity levels are very high, the total uptake of minerals is reduced since plants are unable to evaporate enough water.

• **Photosynthesis**: Humidity levels indirectly affect the rate of photosynthesis because C02 is absorbed through the stomatal openings. At higher daytime humidity levels, the stomata are fully opened allowing more C02 to be absorbed for photosynthesis. Photosynthetic levels can vary by about 5% between VPD's of 2-10 mb.

• **Growth and Quality:** Most greenhouse plants tend to grow better at higher relative humidities. However, mineral deficiencies, disease outbreaks, smaller root systems, and softer growth are possible consequences of excess humidity. There is no one level of humidity that is good for all crops.

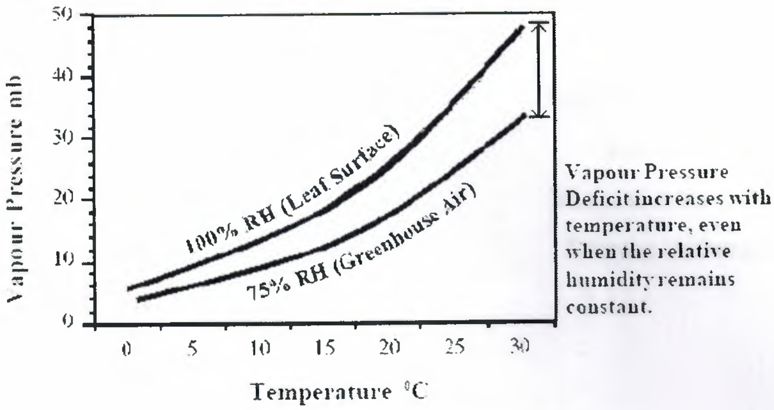


Figure 2.11 **Vapour Pressure Deficit**

Table 2.6 Vapour Pressure of Water in Mb at Various Temp. and Relative Humidities

Temp C	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
15	17.0	16.2	15.3	14.5	13.6	12.8	11.9	11.1	10.2	9.4	8.5
16	18.2	17.3	16.4	15.4	14.5	13.6	12.7	11.8	10.9	10.0	9.1
17	19.4	18.4	17.4	16.5	15.5	14.5	13.6	12.6	11.6	10.6	9.7
18	20.6	19.6	18.6	17.5	16.5	15.5	14.4	13.4	12.4	11.3	10.3
19	22.0	20.9	19.8	18.7	17.6	16.5	15.4	14.3	13.2	12.1	11.0
20	23.4	22.2	21.0	19.9	18.7	17.5	16.4	15.2	14.0	12.8	11.7
21	24.8	23.6	22.4	21.1	19.9	18.6	17.4	16.2	14.9	13.7	12.4
22	26.4	25.1	23.8	22.5	21.1	19.8	18.5	17.2	15.9	14.5	13.2
23	28.1	26.7	25.3	23.9	22.5	21.1	19.6	18.2	16.8	15.4	14.0
24	29.8	28.3	26.8	25.3	23.9	22.4	20.9	19.4	17.9	16.4	14.9
25	31.7	30.1	28.5	26.9	25.3	23.7	22.2	20.6	19.0	17.4	15.8
26	33.6	31.9	30.2	28.5	26.9	25.2	23.5	21.8	20.2	18.5	16.8
27	35.6	33.8	32.1	30.3	28.5	26.7	24.9	23.2	21.4	19.6	17.8
28	37.8	35.9	34.0	32.1	30.2	28.3	26.4	24.5	22.7	20.8	18.9
29	40.0	38.0	36.0	34.0	32.0	30.0	28.0	26.0	24.0	22.0	20.0
30	42.4	40.3	38.2	36.0	33.9	31.8	29.7	27.6	25.4	23.3	21.2

Table 2.7 Vapour Pressure Deficit in Mb at Various Temperatures and Humidities

Temp C	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
15	0.0	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.8	7.6	8.5
16	0.0	0.9	1.8	2.8	3.7	4.6	5.5	6.4	7.3	8.2	9.1
17	0.0	1.0	2.0	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7
18	0.0	1.0	2.0	3.1	4.1	5.1	6.2	7.2	8.2	9.3	10.3
19	0.0	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0
20	0.0	1.2	2.4	3.5	4.7	5.9	7.0	8.2	9.4	10.6	11.7
21	0.0	1.2	2.4	3.7	4.9	6.2	7.4	8.6	9.9	11.1	12.4
22	0.0	1.3	2.6	3.9	5.3	6.6	7.9	9.2	10.5	11.9	13.2
23	0.0	1.4	2.8	4.2	5.6	7.0	8.5	9.9	11.3	12.7	14.1
24	0.0	1.5	3.0	4.5	5.9	7.4	8.9	10.4	11.9	13.4	14.9
25	0.0	1.6	3.2	4.8	6.4	8.0	9.5	11.1	12.7	14.3	15.9
26	0.0	1.7	3.4	5.1	6.7	8.4	10.1	11.8	13.4	15.1	16.8
27	0.0	1.8	3.5	5.3	7.1	8.9	10.7	12.4	14.2	16.0	17.8
28	0.0	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.1	17.0	18.9
29	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0
30	0.0	2.1	4.2	6.4	8.5	10.6	12.7	14.8	17.0	19.1	21.2

Too low	Too high
Dry tip burn	oedema
wilting	Edge burn(guttation)
Small leaves	Soft growth
Stunted plants	Mineral deficiencies
Spider mites	Disease outbreaks
Leaf curl	

2.2.3.5 Dehumidification

In greenhouses, we usually try to avoid humidity levels near the dewpoint since free water condensing onto plant surfaces can promote the growth of disease organisms. Under saturated humidity conditions plants cannot evaporate water from their leaves so the uptake of nutrients such as calcium and boron may be limited. It is important to remember that when the relative humidity reaches 90%, it takes only a slight drop in temperature to reach the dewpoint. The problem is compounded by the fact that not all surfaces in the greenhouse are necessarily at the same temperature as the air. Any surfaces that are cooler than the air at high relative humidities will condense water vapour. That is why dripping can be such a problem with glazing materials during the heating season. Monitoring and controlling the relative humidity of the greenhouse air is not always a guarantee that the dew point will be avoided. Local condensation problems can still occur due to uneven heat distribution and the thermal mass of plant materials, particularly on plants with fruits and other large waterfilled parts. This causes their surface temperatures to lag behind when sudden changes in air temperature occur. It's the same reason a glass of ice water sweats even when the relative humidity of the room air is well below the dewpoint. Cold surfaces within the greenhouse cool the air immediately surrounding them. If the cooling reaches the dewpoint temperature, water condensation occurs. Excess humidity is usually more problematic in the spring and fall seasons when the weather is cool and moist. (See Figure 2.13) High humidities are not likely to occur during freezing weather, since the relative humidity of the outside air is very low. A combination strategy of venting to exchange moist air with drier outside air, and heating to reduce the relative humidity levels, raise the temperature of plant surfaces, and warm the incoming air is usually employed. Glass panes and other cold surfaces in the greenhouse serve as natural dehumidifiers when the outside air is colder, but this, of course, can cause problems with dripping.

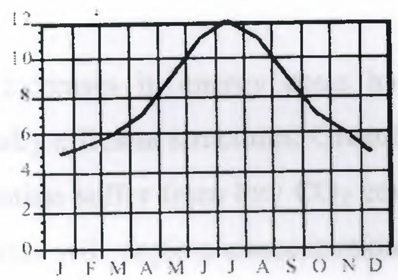


Figure 2.12 average monthly water content of outdoor air H2O grams/m3

2.2.3.6 Humidification

Although dehumidification is sometimes expensive, it is usually easier to reduce humidity levels than to increase them. Raising humidity levels without creating excessive free water requires some sort of evaporative device such as misters, fog units, or roof sprinklers, all of which add water vapour to the air, or screens that help hold in the water that is being evaporated from the plant canopy.

Evaporative devices accomplish 3 things: first, they cool the air, raising the humidity and relieving stress on the crop. Second, they add water vapour to the air, further increasing the relative humidity. And third, they reduce the vapour pressure deficit which is the force that evaporates water from the leaves. Screens may also reduce leaf temperatures and help to trap the large amount of water that the plants are evaporating. Evaporative cooling and screening are often used together. When humidifying under sunny conditions, some venting is necessary since the greenhouse would soon become a steam bath without the introduction of fresh dry air to evaporate more water, and to cool, humidify, and displace hot greenhouse air. Anyone who has stood in an empty greenhouse on a hot summer's day knows that plants, by themselves, can do an excellent job of cooling and humidifying a greenhouse. Evaporative cooling equipment works with the plants, helping relieve some of the transpiration stress and allowing them to grow at optimum rates. The benefits of maintaining a humidification set point include: better plant quality, faster cropping, and lower disease and insect problems.

2.2.4 Carbon dioxide

2.2.4.1 CO_2 Dynamics and Enrichment Techniques

Since 1973, sharp increases in energy costs have dictated that greenhouse operators adopt more thermally efficient structures. Greenhouses designed to cut energy costs by reducing air infiltration suffer from low CO_2 concentrations if supplementary CO_2 is not supplied, as plants will deplete concentrations to photosynthesis- limiting levels within a few hours following sunrise. In order to maintain plant productivity, such greenhouses must either lose thermal energy by directly ventilating or they can employ air-to-air heat exchangers to bring in CO_2 from the outside air, or generate it internally by burning natural gas and other fossil fuels, or utilize compressed CO_2. Common greenhouse vegetable growing practices for centuries depended on manures and other organic matter to decompose in the soil and release generous quantities of CO_2 in the process. The problem of low CO_2 levels in greenhouses has been exacerbated by the shift to hydroponic culture of vegetables, wherein soluble fertilizers are supplied to the roots of the plants contained in soilless substrates that generate no CO_2. The role of CO_2 in plant growth is frequently underestimated. Atmospheric CO_2 levels are the most limiting factor in the growth of most terrestrial plants. Carbon dioxide is as essential to plant growth as water, light levels, soil nutrients and temperature. Plants average about 50 percent carbon by dry weight, deriving most of this carbon from atmospheric CO_2 via photosynthesis. Without CO_2, plants cannot photosynthesize, whether or not other growth factors are adequate. It is estimated that an acre of tomatoes processes about 50,200 tons (4.55 x 107 kg) of air to obtain the 24 tons (21,800 kg) of CO_2 required to produce 70 tons (63,500 kg) of fruit, CO_2 demands of greenhouses range from 5 - 10 grams per square meter per hour (0.001 - 0.002lb/ft2/hr), or 40 - 80 grams per square meter per day, although summer enrichment may require levels far in excess of this. Many Dutch greenhouse vegetable growers are even burning natural gas to supply CO_2 to crops in the summer when vents are wide open, to make up for the tremendous photosynthetic demand of a greenhouse full of tomatoes or cucumbers . Carbon dioxide enrichment has given the most spectacular yield increases of any growth factor yet discovered in the culture of greenhouse crops.

A remarkable increase in yield, improvement in quality and shelf life, and accelerated maturity in all crops has been demonstrated in extensive research. Commercial applications of CO_2 enrichment commonly produce a 20 to 30 percent yield increase when levels are maintained at three to five times ambient concentrations, about 340 parts per million. Optimal enrichment levels for many crops appear to be less than three times ambient concentrations according to recent research that indicates some photosynthetic suppression at levels in excess of 1000 ppm and damage to leaf tissues of some crops at levels ranging from 800 ppm to 1600 ppm.

2.2.4.2 Biological CO_2 Sources

CO_2 from a variety of biological sources has been used to enrich greenhouses for centuries. In addition to composting, alcohol fermentation, anaerobic methanogenesis, and vermicomposting have all been used to raise CO_2 levels by capitalizing on usually wasted byproducts of decomposing organic matter. Another method for application of CO_2 enrichment to greenhouses includes spread the organic material on the greenhouse ground, or incorporating it into the upper soil layer. Chickens and rabbits have been raised in greenhouses for CO_2 and heat contribution, but their manure and urine can cause problems in greenhouses unless ammonia gas is isolated, vented or filtered from the CO_2-rich exhaust air of confined animals or compo sting manures. Many experiments in greenhouse enrichment with compost-evolved CO_2 have concluded that exhaust filtration is required when working with fresh manures and other nitrogen rich feeds tocks that produce ammonia during decomposition.

2.2.4.3 Heat and CO_2 in greenhouses

Greenhouses scattered throughout Europe have been heated and enriched by composting. Pain and Pain (1972) and Schuchardt (1984) have used composting woodchips to heat greenhouses. Both employed matrices of polyethylene or PVC tubes in large piles through which water was circulated by a pump, and then into a nearby greenhouse for heating of the soil.

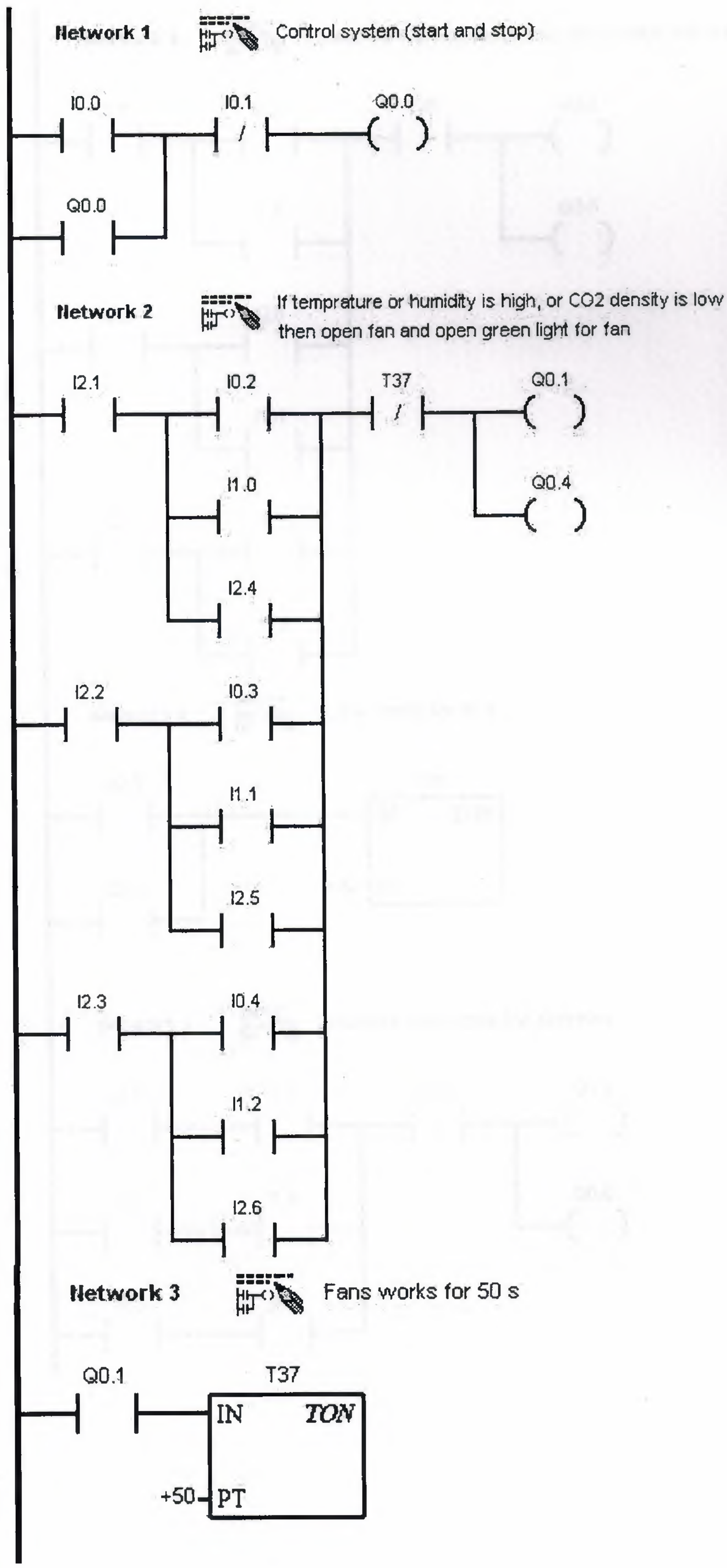
CHAPTER 3

PLC AND THE GREENHOUSES

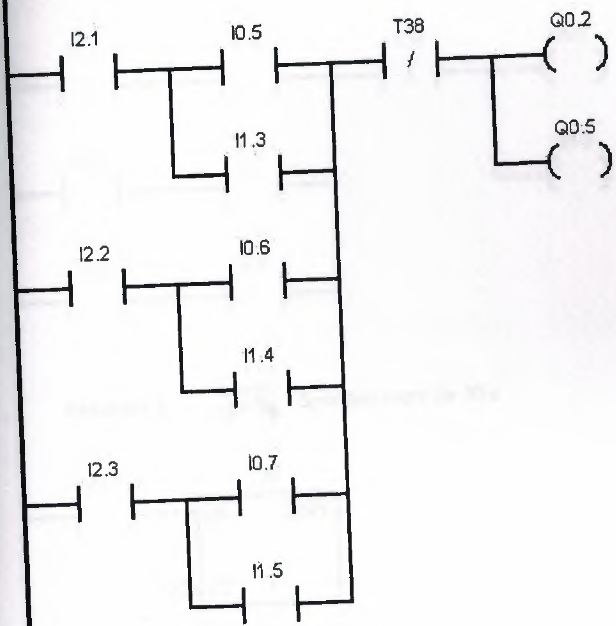
3.1 Ladder Program

Nowadays the PLC has been widely used in many control fields. Because it is easy to program it and with PLC we are able to write the condition which we want our program has to do. In this project the greenhouses has three parameters (Temperature, humidity, CO_2) that should be monitored and controlled continuously. For this reason the PLC is introduced to control them.

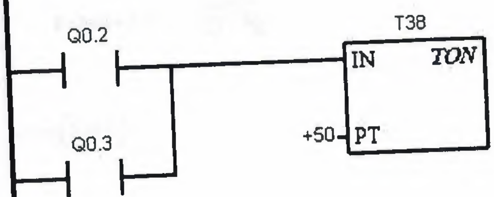
The following ladder program shows how we can control the temperature, humidity and CO_2 using PLC.


Network 1
Control system (start and stop)
I0.0
I0.1
Q0.0
Q0.0
Network 2
If temprature or humidity is high, or CO2 density is low
then open fan and open green light for fan
I2.1
I0.2
T37
Q0.1
I1.0
Q0.4
I2.4
I2.2
I0.3
I1.1
I2.5
I2.3
I0.4
I1.2
I2.6
Network 3
Fans works for 50 s
Q0.1
T37
IN
TON
+50
PT

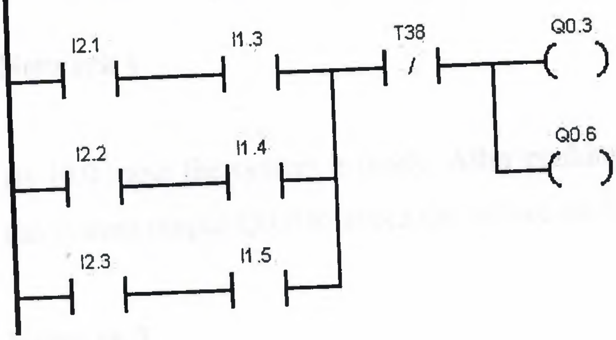
Network 4 If temprature or humidity is low, start heater and open green light for heater

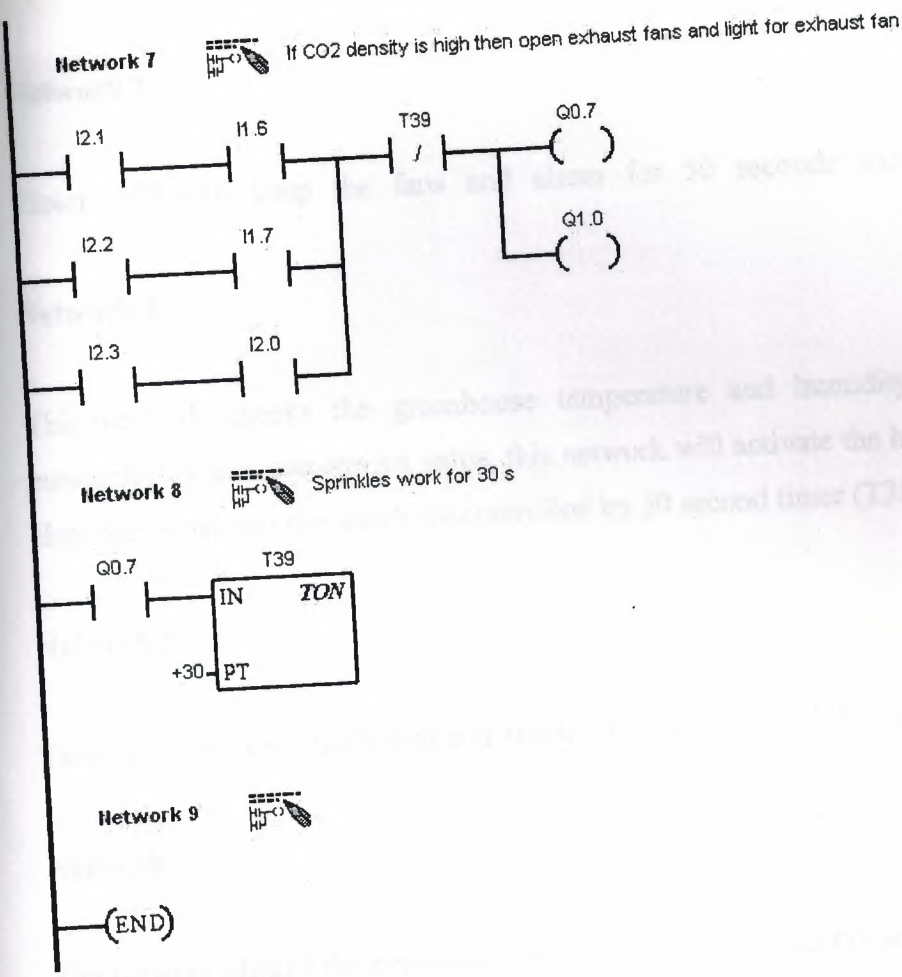


Network 5 Heater works for 50 s



Network 6 If humidity is low open the sprinkles





Network 1

By I0.0 input the system is ready. After pushing the I0.0 button the system is locked by the system output Q0.0 to avoid the failure on I0.0. The system is shutdown by I0.1.

Network 2

This network checks the greenhouse temperature, humidity and CO_2 density. If temperature or humidity is greater than the set value or the CO2 density of air is less than the set value, it will activate the fans and the alarm. Here the fans and the alarm are controlled by 50 second timer (T37).

Network 3

Timer T37 will keep the fans and alarm for 50 seconds and then stop them.

Network 4

This network checks the greenhouse temperature and humidity. If one of these parameters is less than the set value, this network will activate the heater and the alarm. Here the heater and the alarm are controlled by 50 second timer (T38).

Network 5

Timer T38 will keep the heater and alarm for 50 seconds and then stop them.

Network 6

The network checks the percentage of humidity at the greenhouse, if it is below the set value it will activate the sprinkles and alarm.

Network 7

The network checks the percentage of CO2 at the greenhouse, if it is above the set value it will activate the exhaust fans and alarm.

Network 8

Timer T38 will keep the sprinkles and alarm for 30 seconds and then stop them.

Network 9

The program is ending by the end statement.

Table 3.1 Input specifications

I0.0	system start
I0.1	system stop
I0.2	high temperature 1
I0.3	high temperature 2
I0.4	high temperature 3
I0.5	low temperature 1
I0.6	low temperature 2
I0.7	low temperature 3
I1.0	high humidity 1
I1.1	high humidity 2
I1.2	high humidity 3
I1.3	low humidity 1
I1.4	low humidity 2
I1.5	low humidity 3
I1.6	high CO2 1
I1.7	high CO2 2
I2.0	high CO2 3
I2.1	Selection Switch 1
I2.2	Selection Switch 2
I2.3	Selection Switch 3
I2.4	low CO2 1
I2.5	low CO2 2
I2.6	low CO2 3

Table 3.2 Output Specifications

Q0.0	System ready
Q0.1	Fan
Q0.2	Heater
Q0.3	Springle
Q0.4	Light for fan
Q0.5	Light for heater
Q0.6	Light for sprinkles
Q0.7	Exhaust fan
Q1.0	Light for exhaust fans

3.2 Actuators used in this project

3.2.1 Fans

Forced-Air Ventilation

Greenhouses rely on ventilation fans to move air into and out of the greenhouse. Forced air ventilation includes fans on one end of the greenhouse and motorized air inlets, or shutters, at the opposite end. When inside temperatures exceed the desired level, a thermostat opens the shutters and starts the fan(s). Ventilation is accomplished as outside air is pulled into the greenhouse through the shutters, moved lengthwise through the greenhouse and exhausted out by the fans. When the desired temperature has been reestablished, the thermostat shuts off the fans and closes the motorized shutters. Some advantages and disadvantages of mechanical ventilation systems:

Advantages

- They minimize drafts and possible chilling injury on plants.
- They provide more precise environmental control.
- They are easier to fully automate.

Disadvantages

- Fans, shutters and wiring materials add to the initial cost of the greenhouse.
- A continuing expense is the cost of electricity to operate the fans.

Selecting Fans

Fan capacity is measured as the volume of air (cubic feet) moved per unit of time (minute). It is usually expressed as cubic feet per minute (cfm). The amount of air a fan moves depends on the blade diameter, blade shape, fan speed (revolutions per minute, rpm), motor horsepower and the shape of the housing (Table 3.3). The two most common measurements used to describe the characteristics of a fan are blade diameter and motor horsepower. These are useful measurements, but without performance characteristics (airflow and static pressure), these are only general indicators of fan capacity.

Table 3.3 Cubic feet per minute vs. Static Pressure

Fan Size	HP	RPM	0"	.05"	.10"	.125"	.15"
24"	1/4	622	5300	4900	4500	4200	3900
	1/3	735	6200	6000	5700	5500	5300
	½	820	7000	6700	6500	6300	6100
	3/4	949	8100	7800	7600	7500	7400
30"	1/3	529	8500	8000	7400	7000	6600
	1/2	607	9700	9300	8800	8600	8300
	3/4	686	11000	10600	10200	10000	9800
36"	1/3	421	10300	9600	8800	8300	7700
	1/2	495	11800	11200	10600	10200	9800
	3/4	575	13700	13200	12700	12400	12100
	1	634	15000	14600	14200	14000	13700
42"	1/2	385	14000	13600	12500	11800	11100
	3/4	442	16600	15900	15000	14500	14000
	1	485	18200	17500	16800	16300	16000

Airflow rate (cfm) and static pressure are closely related for fans and ventilation systems. The air-moving capacity of a fan (cfm) is directly affected by the system static pressure. As the resistance to airflow (static pressure) increases, the delivered airflow capacity decreases. Hence, a fan delivers more air against a low static pressure than against a high static pressure. Typically, the system resistance is about 0.1 to 0.125 inches of water. For this reason, ventilation fans are typically selected to deliver the desired airflow at 0.125 inches of water (1/8") static pressure.

3.2.2 Heaters

Localized heat systems are 3 types

- Unit or forced air heaters
- Radiant or infrared heaters
- Convection heaters

Unit or forced air heaters (rated by the number of BTUs/hr)

Made up of a:

- Firebox for fuel combustion
- Heat exchanger surface
- Fan for heat distribution
- Exhaust pipe for products of combustion

- Source of air for combustion (preferably from outside)

The fuel supply, burner and the fan are thermostatically controlled.

Allows for efficient placement of heaters were they are needed. Independent sections of Greenhouses can be easily controlled and added. Initial cost is low - about $1 to 1.5/ft2. Fuel is higher cost, usually natural gas or propane. Heat distribution by convection tubes or some other method. Harder to keep the heat down low in the greenhouse.

Must be vented to provide adequate oxygen supply, 1 square inch of vent per 2500 BTU recommended. For a 125,000 BTU heater, 50 in2 or and 8 inch diameter pipe would be required. Need to have the waste gases vented. Fumes can be toxic to employees and plants if combustion is incomplete or contaminants are present in the fuel. Some growers will try to vent into the greenhouse to take advantage of the CO_2 and heat. This is not recommended. Cracks in the heat exchanger or exhaust can also release toxic fumes. Flames should be checked and adjusted regularly.

Radiant or Infrared heaters

Large ceramic surfaces in the case of electric units or large metal pipes in the case of gas fired units are heated to very high temperatures and the heat is lost by radiating to the environment. Radiant heat energy can move through air without heating the air significantly. The radiant heat strikes object and the heat is transferred to that object. These systems were more popular during the energy crisis because by heating the plant and not the air, there was less heat loss from the greenhouse. Air temperatures run 5 to 7 degrees F cooler than normal. The efficiency of operation is higher than boilers (90% vs 70 to 75%) and the exhaust temperature is usually much lower (<150 F vs 400 to 600 F). The units were affordable, but no one really knew how long they would last in the greenhouse.

Problems have been with providing uniform heat and properly sensing the plant temperature. Since the air is cooler, normal thermostats are not as affective. Not good for melting snow so a backup system is normally needed.

These systems are not very widely used but they do have some advantages and some use in special cases. Since the plant is warmer than the air, there is not a problem with moisture condensation on the leaf surface.

Parts:

- Heater (size varies from 20,000 to 120,000 BTU)
- Reflectors
- Pipe (4 inch by 20 to 30 feet long)
- Vacuum pump to draw warm air through the pipe and exhaust it out the greenhouse

3.2.3 Sprinklers

3.2.3.1 Sprinkler types

Sprinklers that spray in a fixed pattern are generally called sprays or spray heads. Sprays are not usually designed to operate at pressures above 30 lbf/in² (200 kPa), due to misting problems that may develop.

Higher pressure sprinklers that rotate around themselves are driven by a ball drive, gear drive, or impact mechanism. These can be designed to rotate in a full or partial circle. Some sprinklers are also known as Floppy Sprinkler, Spray Pop-ups, pulsating sprinklers due to their water stream and Revolutionary new concept having no rotating or moving parts.

Figure 3.1 a rotary irrigation sprinkler in action.

Rainguns are similar to impact sprinkler, except that they generally operate at very high pressures of 40 to 130 lbf/in² (275 to 900 kPa) and flows of 50 to 1200 US gal/min (3 to 76 L/s), usually with nozzle diameters in the range of 0.5 to 1.9 inches (10 to 50 mm). In addition to irrigation, guns are used for industrial applications such as dust suppression and logging.

Many irrigation sprinklers are buried in the ground along with their supporting plumbing, but above ground and moving sprinklers are also common. Most irrigation sprinklers are functioned through electric and hydraulic technology and are grouped together in zones that can be collectively turned on and off through actuating a solenoid valve.

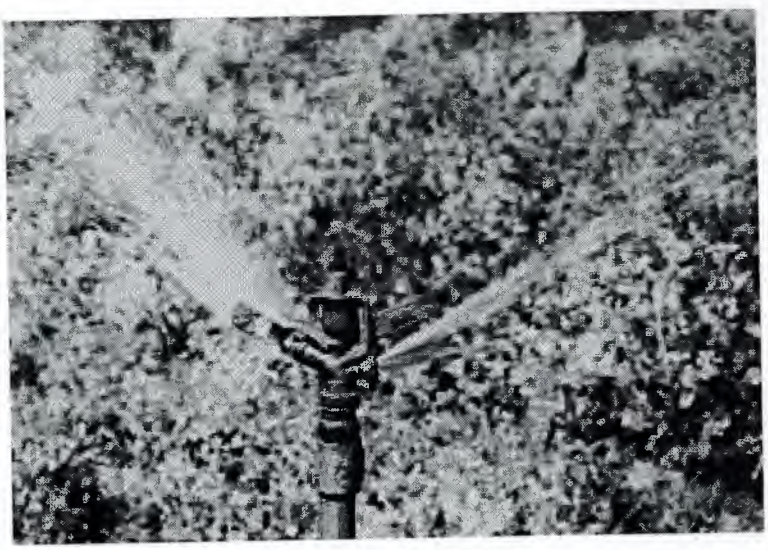


Figure 3.2 Spray Head

3.2.3.2 Sprinkler use

Most irrigation sprinklers are used as part of a sprinkler system, consisting of various plumbing parts, piping and control equipment. Piping is connected to the water source via plumbing fittings and the control system opens and closes valves to provide water on a schedule. The control provided varies depending on the equipment used; some systems are fully automated and even compensate for rain, runoff and evaporation, while others require much more user attention for the same effectiveness.

CONCLUSION

In this project we gave information about PLC control systems, how they are working, their advantages and disadvantages. PLC and PC based control system are compared, their similarity and difference discussed. Temperature, humidity and carbon dioxide sensors are explained.

Types of Greenhouse Structures and specific requirements of the greenhouses are explained.

A PLC program has been designed to be able to control a greenhouse by using temperature sensor, humidity sensor and carbon dioxide sensor, and it's done by fans, heaters and sprinkles.

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