AUTOMATED ENVIRONMENTAL PRECONDITIONING
FOR
EFFICIENT PLANT GROWTH

A MASTER'S THESIS

in

Electrical and Electronic Engineering

Gaziantep University

By

Ulus CEVIK

October, 1990

Approval of the Graduate School of Natural and Applied Sciences

Prof.Dr. Mazhar UNSAL

Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Prof.Dr. Muhammet KOKSAL

Chairman of the Department

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Assoc.Prof.Dr. Celal KORASLI

Supervisor

Examining Comittee in Charge:

Prof.Dr. Tuncay EGE (Chairman)

Assoc.Prof.Dr. Celal KORASLI

Assoc.Prof.Dr. M. Saadettin OZYAZICI

ABSTRACT

MICROCOMPUTER-AIDED GREENHOUSE CONTROL

CEVIK, Ulus
M.S in Electrical and Electronic Engineering
Supervisor: Assoc.Prof.Dr. Celal KORASLI
October 1990, 62 pages.

The main purpose in greenhouse plantation is to provide environmental factors affecting the growth, such as temperature, relative humidity, light, and water, to the best of plant needs. This form of greenhouse conditioning also eliminates adverse effects oriented from the atmosphere.

In this work a system is designed to control greenhouse atmosphere and soil moisture. The automation is realized using an 8-bit microcomputer and some driving units.

According to the type of plant to be grown a range set for each parameter and the measured values were compared.Any deviation from the range activates the related control unit, for example, when the measured temperature drops to a value below the range set heat blower is activated .

In the case of any failures or malfunctions resulted in the control circuits an audio alarm facility is also supplied to the system.

Keywords: Greenhouse, Microcomputer automation.

ÖZET

MİKROBİLGİSAYAR YARDIMLI SERA KONTROLU

ÇEVİK, Ulus
Yüksek Lisans Tezi, Elektrik ve Elektronik
Mühendisliği Bölümü
Tez Yöneticisi: Doç.Dr.Celal KORAŞLI
Ekim 1990, 62 sayfa.

Seralarda genel amaç bitki gelişimini etkileyen sıcaklık, bağıl nem, ışık ve su gibi faktörlerin yeteri kadar ve mevsim değişimlerinden izole olmuş şekilde sağlanmasıdır. Bu şekilde atmosferden kaynaklanan olumsuz etkiler ortadan kaldırılır.

Bu çalışmada sera atmosferi ve toprak suyu kontrolü 8-bitlik bir mikroişlemci ünitesi kullanılarak otomatize edilmiştir. Bu işlem oldukça basit bir algoritma ve mikroişlemci ünitesine ek olarak tasarlanmış elektronik devreler kullanılarak gerçekleştirilmiştir.

Üreticinin yetiştireceği bitki tipine göre seçeceği ideal değerler sera içinde algılayıcılarla elde edilen değerlerle karşılaştırılmakta ve bu değerlerden sapmalar olduğunda ilgili birimler uyarılarak ideal değerlere ulaşmak için gereken önlemler alınmaktadır. Bu önlemler sıcaklık düştüğünde bir ısıtıcının çalıştırılması veya arttığında ventilasyon devresinin uyarılması gibi işlemlerden oluşmaktadır. Ayrıca kontrol birimlerinde ortaya çıkabilecek herhangibir arıza sonucunda aşırı durumları haber veren sesli alarm olanağı da sunulmuştur.

Anahtar kelimeler : Sera, Mikrobilgisayarlı otomasyon

ACKNOWLEDGEMENTS

I want to express my thanks to my supervisor, Assoc. Prof. Dr. Celal KORASLI for his suggestions, encouragement, his great help in the preparation of this work, and above all, for his friendship.

The author also wishes to extend his tanks to Mr. S. Tilfarlioglu for valuable helps in mechanical parts, to Mr. M. Konu for metallic constructions, to Mr. H. Gerez for drawings, and to Mrs. N. Habesoglu for typing.

LIST OF FIGURES

LIST OF TABLES

CONTENTS

CHAPTER 1 INTRODUCTION

1.1 General

Maintaining appropriate environment for greenhouse plants may be obtained by gently balancing their various requirements, such as water, minerals from the soil, light, warmth, a moist atmosphere, and clean air. Not all kinds of plants need the same degree of heat, wetness , or light, so it is necessary to understand the particular requirements of plants to be grown. Certain species used to a dry climate will resent too much water, and but those from a wet one will shrivel if the air is too dry. Also certain kinds used to cool climates may suffer from heat in a greenhouse adjusted to the needs of those from a warm climate.

Each aspect of the environment factors requiring attention affects also the other factors. There is a fine interrelation between light, heat, and humidity, and between temperature and frequency of watering, and the latter is in turn related to the type of soil.

The main purpose of environmental control of greenhouse climate has been automation using motors, fans, heaters, irrigation pumps, etc. Therefore, the controllers needed not only to make the environmental parameters close to the set values,but also to maintain interplay between parameters.

The use of microcomputers for controlling the environmental factors in greenhouses have proved to be sucessful because of the flexibility of changing the set points of controlled variables, possibilities of data acquisition and alarm functions.

1.2 Previous Studies

In most control systems being designed for climate control in greenhouses, a microcomputer based automation was applied for either partial or full control of environmental factors.

In this section some of commonly used automation methods are reviewed in their order of importance for best plantation.

In the method developed by A.Kano and H.Shimahi [4] a crop model and an expert system were used to control greenhouse climate. The center to the expert system is a microcomputer unit for data processing, and control purposes. Necessary modifications on the control program was made to set several environmental factors into the model system.Inputs to the system were solar radiation, air temperature and CO_2 concentration.

Controlled manipulators were window motors, mist pumps, irrigation pumps, heat pump, and CO_2 valves.

J.C.Bakker [4] studied on greenhouse climate control by a distributed computer system in which he used three levels of microcomputers linked by a local area network.

Level "0" was situated near greenhouse for measuring data, level "1" was for processing the data, and level "2" was for storing the data for statistical purposes. This design was applied to control 9 greenhouses with over 75 different compartments.

In the work of Pierce Jones, B.K.Jacobson, and J.W.Jones [4] an autonomous dynamic controller that selects set points for the frequency and duration of misting events was developed and tested. The set points were chosen by an expert system, MISTING, that was based on the perceived optimal misting strategy of an experienced grower. System software ran on a general purpose microcomputer (IBM-PC) that was located 0.5 km from the greenhouse. The remote microcomputer communicated via a dedicated telephone line.

K.Kurata [4] developed a system which learns grower's greenhouse control methods by measuring environmental factors, crop status, and grower's behaviour and later the learned rules were applied to the automatic greenhouse control. Simply the system was designed to imitate the grower.

At the end of the study an algorithm called K-algorithm was developed.

A classical approach to the design was made by Priva Company [5] in the University of Cukurova. This system was operated according to the algorithm as follows:

i) measurement of greenhouse parameters,
ii) comparison of measured values with the preset ones.
iii) activation of related control units to arrive preset values in the range of tolerances, if deviations occurs.

The units to control heat were ventilation flaps and fans, water pads, shading system, heater, and heat screens.

Relative humidity control was done by means of the ventilation system, water pads, and misting pumps.

Extended period of day-light, required for photosynthesis, is supplied by sodium lamps mounted in the greenhouse.

CHAPTER 2 ENVIRONMENTAL CONTROL ASPECTS

Greenhouse conditioning is achieved by attuning several environmental factors, such as relative humidity, temperature, soil temperature and its humidity, and if required extended lighting period.

In the following sections type of processes needed to be controlled for providing necessary environmental factors in a greenhouse are summarized [1].

2.1 Ventilation

Ventilation is necessary both to bring fresh air to the plants and to provide air exchange for controlling summer heat. A greenhouse can become an oven if it is left closed when the sun is shining. There are numerous ways to provide ventilation. The simplest is by means of sections on both sides of the ridge that can be opened and closed by hand. Side ventilators are also helpful, allowing a flow of cooler air from near ground level up and out through the top. These can be automated by motors that respond to a temperature sensor. In addition to this shading, either by painting the glass with whitewash or by installing various kind of sun screens may also become necessary in summer to reduce the heat.

As an alternative method, an exhaust fan may be installed above plant level at one end of the greenhouse and a jealousy (a shutter with horizontal slats that swing open freely) at a lower level at the opposite end. With automatic controls the fan goes on when the temperature in the greenhouse exceeds the temperature setting, and flaps of the jealousy open as the fan reduces the inside pressure. Thus, the hot air is pulled out and replaced with cooler air from outdoors.

Even with shading and ventilation, the summer temperatures may still be too high for best growth of greenhouse plants. An evaporative cooling system may solve this problem. A blower draws air into the greenhouse through the wet pads so that outside air is pulled through it and blown into the greenhouse. In thiscase a ventilator must be kept lightly open at the other end (or a jealousy installed) so that the air can move on through it, maintaining a constant current of cooled air.

2.2 Heating

Although plants require a lower temperature at night than during the day, they do best when it remains even during both periods. Hence, any heating system should be controlled by a sensitive controller. To guard against dangerous extremes caused by power or fuel failure a temperature alarm should be installed. This is an alarm that rings when the temperature goes below or above the desired levels set on.

2.3 Watering

All the biological and microbiological activities of plants take place in the presence of water; minerals in the soil must be in solution before roots can absorb them, and the chemical reactions in cells themselves, such as food making and manufacture of myriad products, and movement of these materials from cell to cell, all go in water solutions. Thus, when water is lacking, plant growth ceases.

Over watering results in literal drowning. Air must be present in the soil along with water, for plants need oxygen at the roots. If the spaces in the soil are continually filled with water to the exclusion of air, oxygen will be deficient and the roots will be unable to carry on respiration. They will cease to carry on their normal function of absorbing water and minerals.

Root death will follow if the condition goes on too long. For best watering let the soil dry before watering again.Since the water fills the air spaces momentarily, and then as some drains away and as the plant use it, the air spaces open up and draw in fresh air.

2.4 Relative Humidity

The amount of moisture in the air plays an important role in the growth of plants. When the air is dry-that is, when the relative humidity low-plants lose water rapidly through their foliage and stems. This loss of water as vapor we call transpiration. Transpiration is high when the air is dry, the temperature warm, the day bright, and the air moving. When the relative humidity is high, transpiration is decreased. Hence, it is required to keep the air humid in the greenhouse. The ideal relative humidity is between 50 and 70 per cent. (At higher relative humidities plants grow well, but there is greater danger of disease getting started.) The humidity can be increased by spraying water in the greenhouse.

2.5 Lighting

When it comes to the use of artificial light for modifying plant growth, the effectiveness of the radiation depends not only on its intensity but also on its spectral characteristics. It also depends upon when the light is being used.

A distinction must be made between three sets of conditions:

(a) a long day, consisting of a single period of light per day with a relatively high illumination level,

(b) a day length extension, which involves two light periods, one following immediately upon the other and consisting of (i) the main light period with a relatively high illumination level and (ii) the extension period during which comparatively low illumination levels and,

(c) the night break, which again involves two light periods (i) the main light period as in (b) above and (ii) a short period of light of relatively low illumination level used to divide the dark period into two shorter periods.

CHAPTER 3 CONTROL SYSTEM DESIGN

3.1 General

Maintaining an appropriate greenhouse environment requires control of several parameters according to the kinds of plant to be grown, as explained in Chapter 2. Sustaining continuous interrelation among these parameters is a complex scheme that requires a microcomputer based automation system. In the following sections the design of a control system supported with a microcomputer was explained.

3.2 Block Diagram Of The System

The block diagram of the system is shown on the Fig. 3.1. The system is divided into four main blocks according to their functions:

i) MPU,
ii) sensor-controller interface,
iii) sensors, and
iv) activators.

Operation of the system considering different function of each block is simply as follows:the sensors senses related environmental variables, the interface converts these data into digital form, then the MPU processes the data and activates or unactivates the actuators accordingly.

In the following sections function of each block will be explained in detailed in the guidance of the block diagram presented.

Operation of the system for a particular plantation was performed according to the order given in Chapter 2.

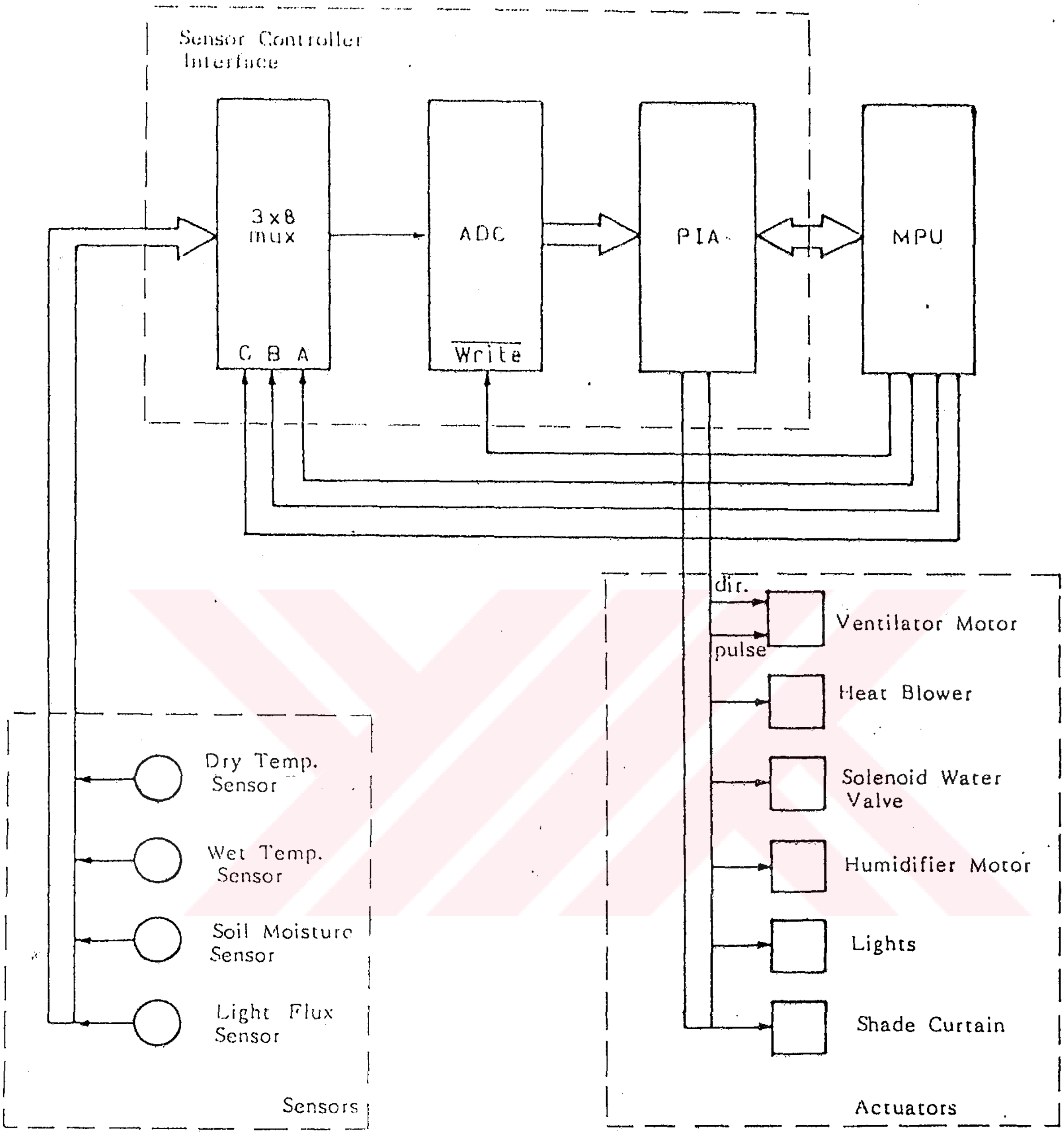


Figure 3.1 Block diagram of the system.

3.3 MPU

The microprocomputer unit ATARI 800 XL® home computer was used in the design of the system. This selection is one of the main purposes of requirements in this thesis, that is to verify the possibility of controlling parameters in a greenhouse with the usage of a home computer. In addition to its avaiability, compatibility with both CMOS and TTL integrated circuits are further features for its selection.

Heart of the microprocessor unit is CMOS MOTOROLA 6502® microprocessor which has 8-bit word-length and 1.5 MHz. processing speed.

CMOS technology associated with the processor makes it to become fully compatible with TTL chips, and this brings the advantage of flexibility in design with both TTL and CMOS integrated circuits. Hence, in the present design several of integrated circuits used are selected from TTL logic family.

The microcomputer has a 6520 PIA, one of its ports has been brought to two joy stick jacks (4 bits in one jack, 4 bits in the other), second port has been left unused.

For data logging a 5.25 inch disk drive, a tape unit and a printer are additional utilities provided to system.

3.4 Sensor-Controller Interface

The interface consists of an 8-bit 6821 peripheral interface adapter (PIA), an 8-bit analog to digital converter and an 8 by 1 analog multiplexer as shown in Fig.3.2.

The analog signals received from the greenhouse environment are multiplexed first before conversion to digital form then interfaced to the MPU for processing. The analog multiplexer makes the system cost effective by reducing the the number of A/D converters. The only disadvantage is the requirement of selection signals (A, B, C) which are supplied from the internal PIA of the microprocessor unit through one of the joy stick jacks. Accordingto the level of the selection signals (high or low) one of the input lines is directed to the output of the multiplexer.The order of selection is done according to Table 1. When the data is selected the "$\overline{\text{Write}}$" strobe of the A/D converter goes low first to latch the converted signal to provide stability, then this low level at the strobe disables the clock pulses supplied to the A/D converter by eliminating loss of initial values resulted from flickering in the digital output. This strobe signal is also supplied from the internal PIA of the MPU just like the selection signals of the multiplexer.

C B A	Output
0 0 0	I_0
0 0 1	I_1
0 1 0	I_2
0 1 1	I_3

Table 1 Truth table of the multiplexer.

The external PIA has been connected to parallel port of the MPU through the address decoder logic (Fig.3.3) This allows the PIA to be addressed that is not present in the operating system.

The address decoder consists of an 8-input NAND gate and a couple of NOT gates.

Port B of the PIA has been programmed as input to accept the data coming from the sensors and Port A as output to set on/off the controllers.

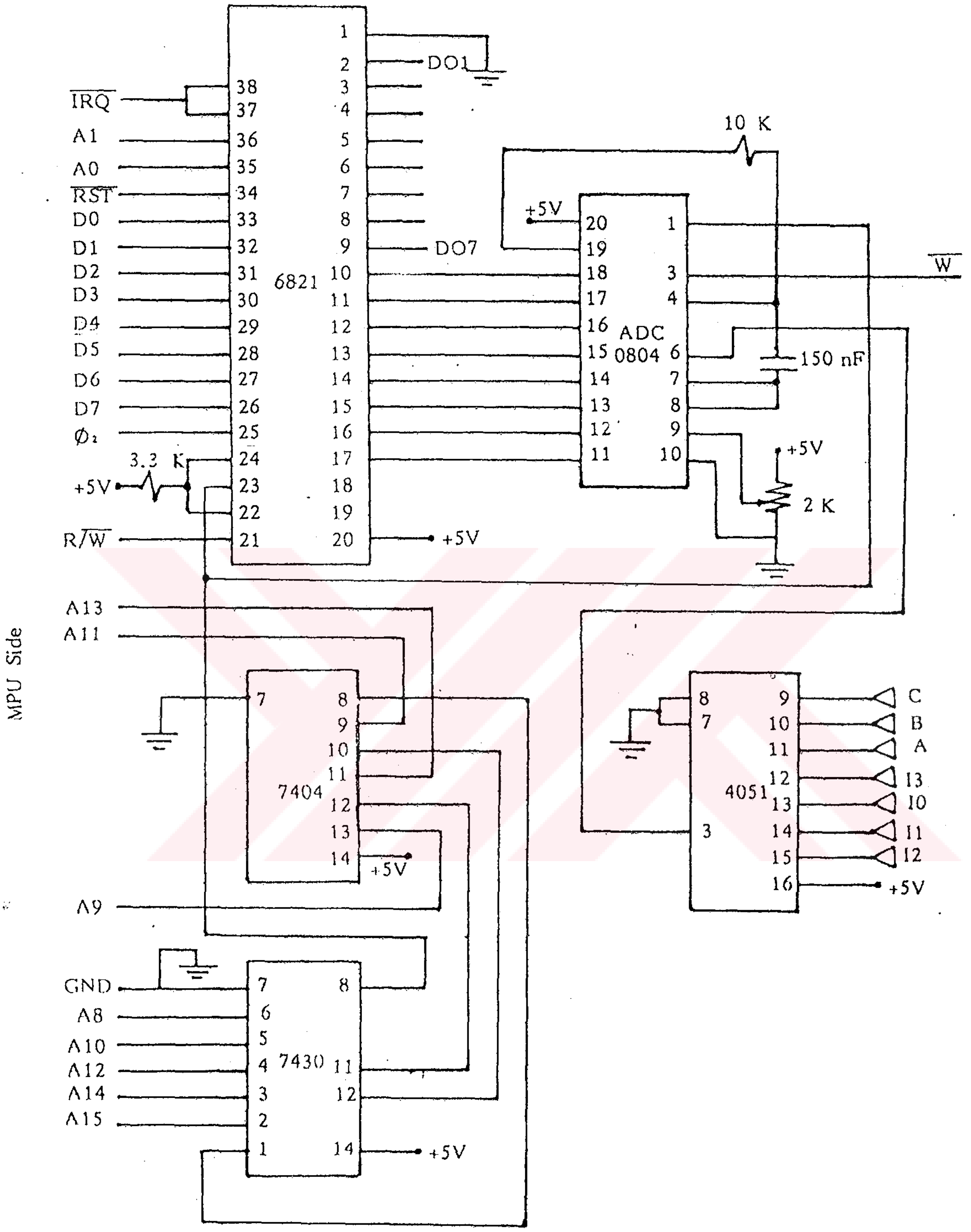


Figure 3.2 The sensor-controller interface circuit.

One of important setting in the sensor-controller interface is the adjustment of the $V_{ref}/2$ voltage of the A/D converter. This is achieved by adjusting the trimmer potentiometer connected to the pin 9 of the A/D converter. The decimal equivalent of the digital output of the A/D converter is given by Eqn.(3-1). This equation will also be used in the software design to decide for the value of measured variable.

$$(\text{Output})_{10} = \text{Int}\left[\frac{V_{in}}{2 * \dfrac{V_{ref}}{2}} * 256\right] \qquad (3\text{-}1)$$

To clarify the possible error caused by this adjustment, let this voltage is set to 1 volt. For an input voltage of 0.751 volt the digital output in decimal form is

$$\text{Output} = \frac{0.751}{2*1} * 256 = 96.128$$

The fractional part of this result will be lost during processing. This is due to unsigned magnitude representation of 8-bit word structure in an 8-bit microprocessor. The error for an input voltage of 0.751 V. due to this forced truncation is

$$\frac{96.128 - 96}{96.128} * 100 = 0.133 \ \%$$

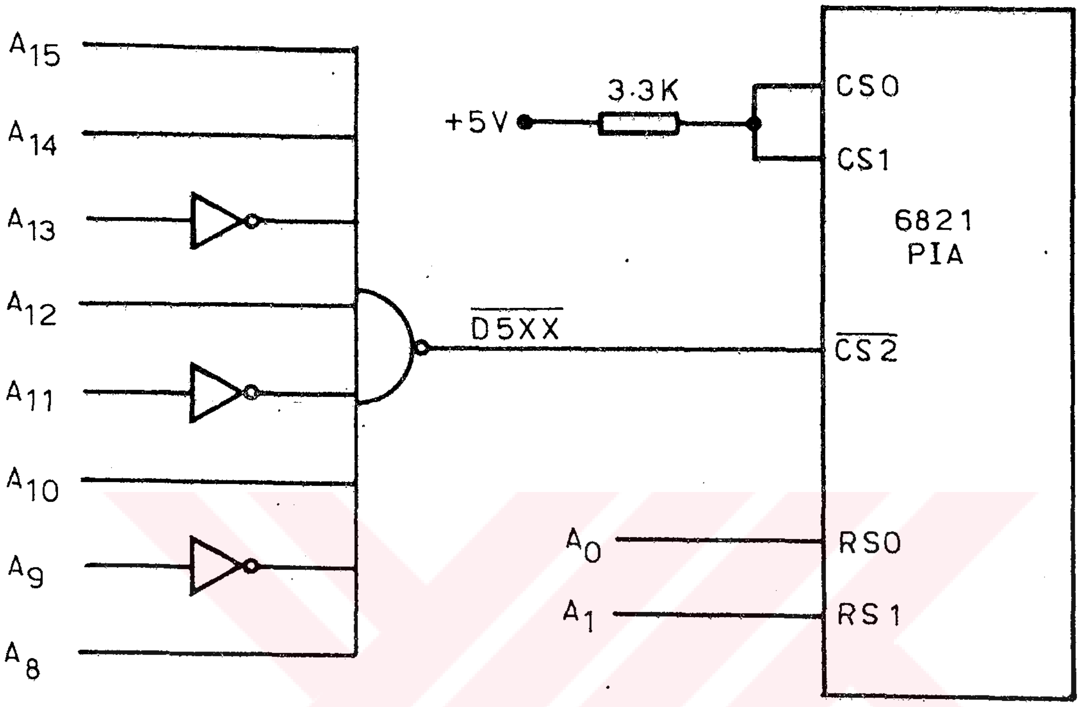


Fig.3.3 Address decoder-PIA Connection.

For addressing the PIA, address bus to PIA interface is arranged according to Fig.3.3.

$\overline{CS2}$	CS1	CS0	RS1	RS0	Selected Port & Register
0	1	1	0	0	Port A, Data Direction/Data
0	1	1	0	1	Port B, Data Direction/Data
0	1	1	1	0	Port A, Control
0	1	1	1	1	Port B, Control

Table 2 PIA selection table.

According to this table and our address decoder the corresponding hexadecimal and decimal addresses of the PIA respectively are;

D500	54528	Port A, DDR/DR
D501	54529	Port B, DDR/DR
D502	54530	Port A, CR
D503	54531	Port B, CR

3.5 Sensors

The system accommodates four sensors to measure temperature, soil moisture, relative humidity, and light flux. They are connected to the sensor-controller interface either directly or through leveling series resistor as shown in Fig.3.6. In the following sections detailed information on each sensor and its calibration procedure will be given.

3.5.1 Temperature Sensor

A LM 35 precision temperature sensor is used to detect temperature in the range between 0 and 100 °C. The sensor has three terminals, one is for supply voltage (4 to 20 volts), and the second is used as output (producing analog voltage between 0 and 1, directly proportional to temperature), and the third is for the ground. By observing the calibration curve shown in Figure 3.4 one can easily deduce the characteristic equation as:

$$V_o = \frac{T}{100} \qquad (3\text{-}2)$$

where,

V_o : Output voltage of the sensor.
T : Temperature in °C.

This equation will be used in the software for voltage-to-temperature conversion.

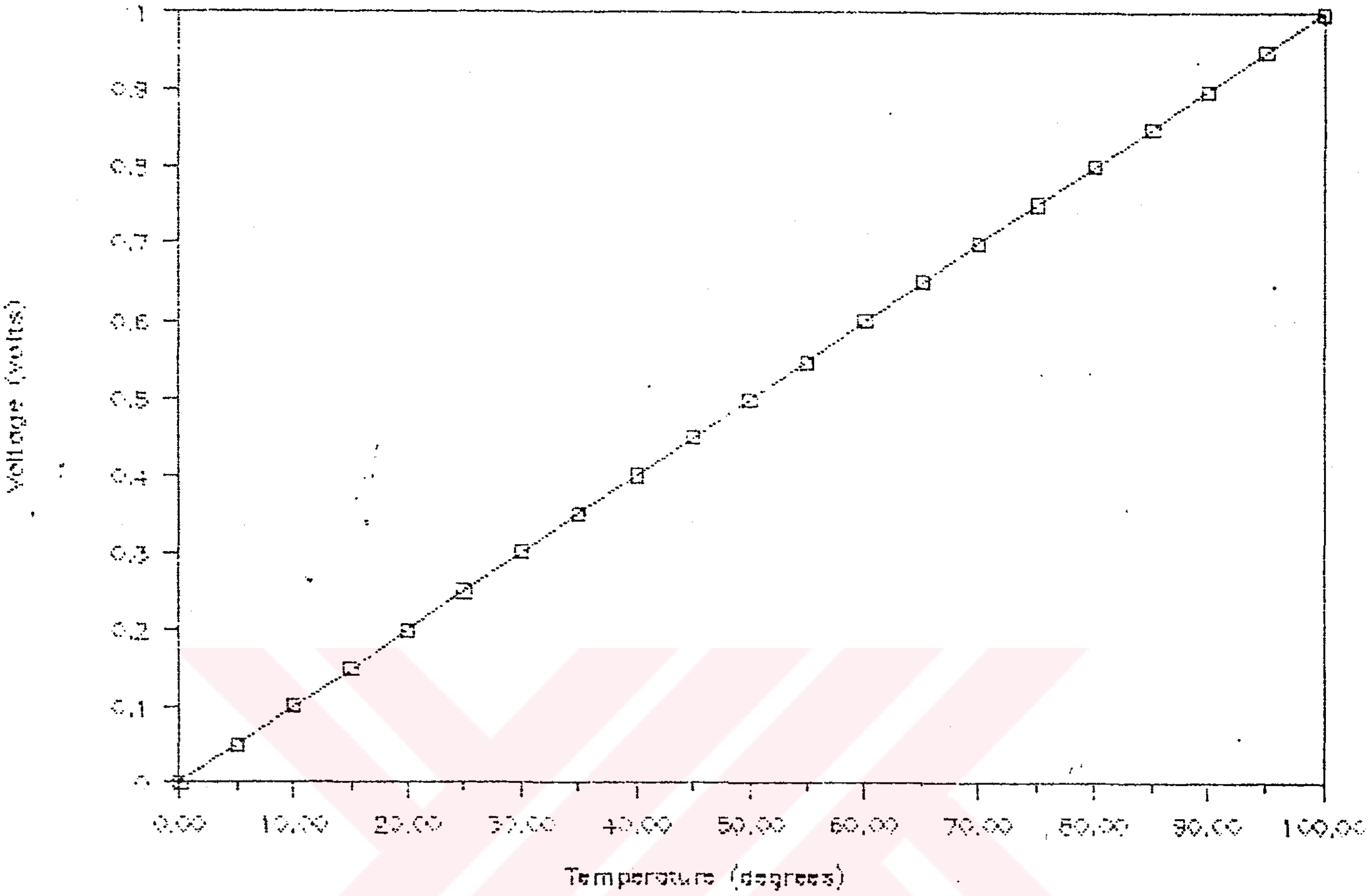


Figure 3.4 Calibration curve of LM 35.

3.5.2 Soil Moisture Sensor

Soil moisture sensor is a dew point sensor (used in videotape players) whose resistance is varies with the moisture as shown in Fig.3.5.

This property brings the idea of sensing the moisture content of soil but preserving its original properties. Therefore the sensor is covered by plaster to prevent it from external damage in the soil and to expose it to a uniform moisture.

The sensor is calibrated by using a bowl of soil, some water, an ohmmeter, and an infrared moisture meter which measures moisture content of a substance in percent by weighting automatically the substance before and after evaporating its moisture.

First the sensor is buried into the soil in the bowl and its resistance is measured by means of the ohmmeter then a soil sample is placed into the moisture meter and moisture content is measured. Resistance and moisture content are recorded. Second, some water is added into the soil and after a while the same procedure above is followed. The calibration curve of the soil moisture sensor obtained is shown in the Figure 3.5.

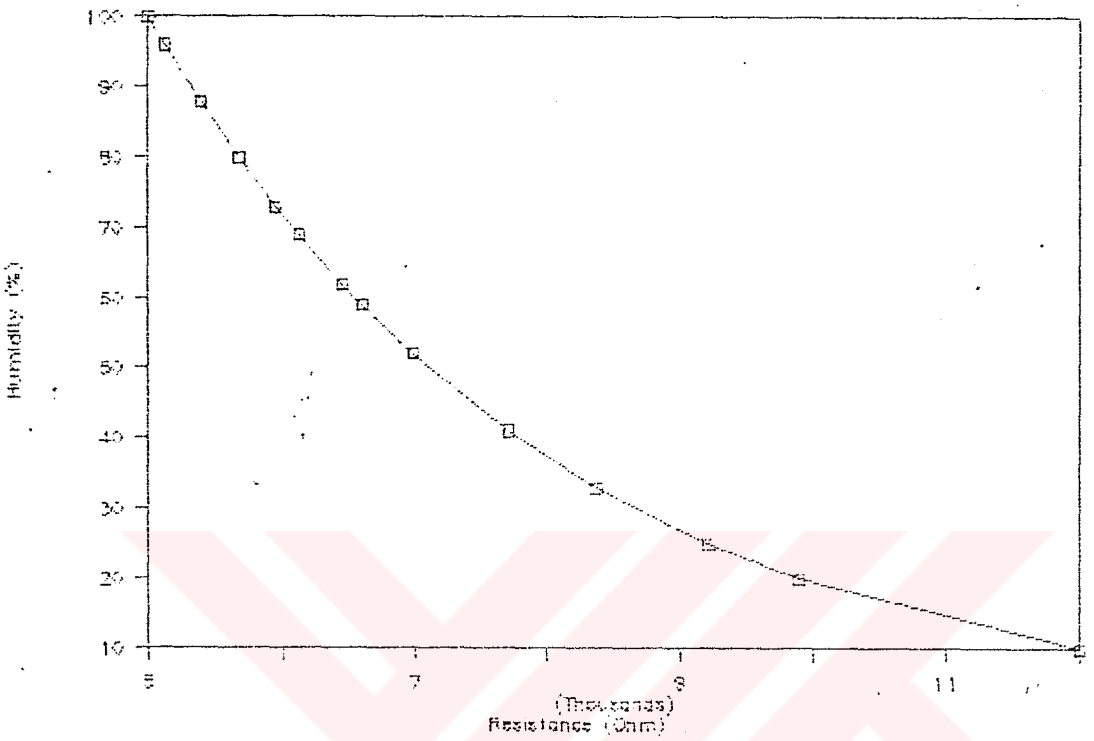


Figure 3.5 Calibration curve of the soil moisture sensor.

In order to interface the sensor to the sensor-controller interface a proper series resistance should be connected as shown in Fig.3.6 such that corresponding voltage on the sensor becomes proportional to the moisture content. For this purpose a potentiometer is connected in series between the sensor and the reference voltage source. The potentiometer is adjusted so that the maximum voltage on the sensor becomes equal to V_{ref}. Thus the voltage on the sensor is proportional to its resistance.

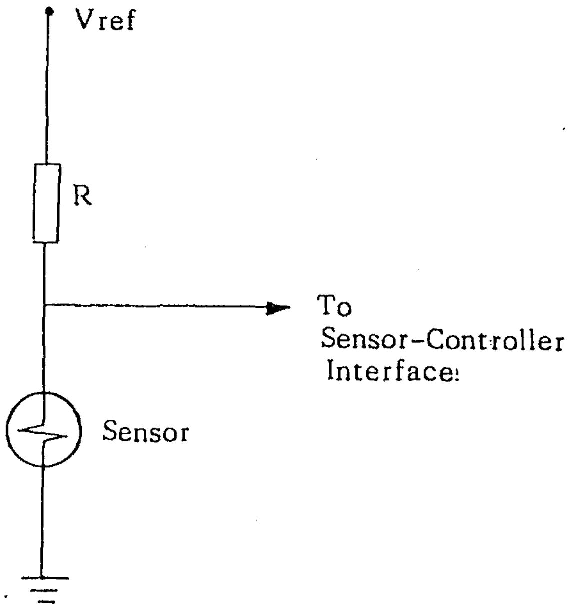


Figure 3.6 Resistance to voltage converter.

The output voltage of this converter circuit is proportional to the resistance of the moisture sensor (R_s) as

$$V_o = \frac{V_{ref}}{R_s + R} * R_s \qquad (3\text{-}3)$$

3.5.3 Relative Humidity Sensor

Percentage ratio of partial pressure of vapor in the air to saturated vapor pressure at a given temperature is called as "relative humidity". It is measured using two temperature sensors one is dry and other is wet type.

For temperature measurements two LM 35 type temperature sensors were used. Wet sensor may be obtained by wetting a normal sensor using some wick dipped into a water container.

When water evaporates it causes the temperature on the wet sensor to decrease. If the vaporization rate is high then the temperature decrease will also be high on the wet sensor. However, since the vaporization rate depends upon the current humidity of air, vaporization rate will be high if the relative humidity is low, so the temperature decrease on the wet sensor is high. Thus this affects the difference between temperatures of the sensors.

In order to calculate relative humidity we need partial vapor pressure and saturated vapor pressure at a given temperature. Saturated vapor pressures at different temperatures have been obtained empirically and given in Table A3. Partial vapor pressure is given by Eqn. (3-4).

$$e = E - (t_d - t_w) f(h) \qquad (3\text{-}4)$$

where

e: partial vapor pressure (mb)

E: saturated vapor pressure at a given wet temperature (mb)

t_d: dry sensor temperature

t_w: wet sensor temperature

f(h): a constant depending upon elevation and wind speed.

f(h) constant can be calculated by the empirical formula:

$$f(h) = 1.6 * (0.76 - h * 8.0 * 10^{-5}) \qquad (3\text{-}5)$$

where h is elevation in meters.

E is obtained from Table A1. t_d and t_w are measured by dry and wet sensors respectively, and f(h) can be found by using Equation (3-5). Thus relative humidity is obtained by just multiplaying the ratio of e/E by 100.

3.5.4 Light Flux Sensor

Light flux is simply sensed by a photoresistor. The resistance of the photoresistor varies nonlineraly according to the light flux as shown in Fig. 3.7. As explained in section 3.4.2 the photoresistor must also be connected to the sensor-controller interface using a resistance to voltage converter using similar connection as shown in Figure 3.6.

The calibration of the sensor was done by means of a lamp hung at a determined height by considering its average flux in terms of W/m^2. The lamp was considered as a point source and assumed to illuminate a square area whose sides equal to twice the height of the lamp. The height of the lamp is changed sequentially and corresponding sensor resistance is measured by means of an ohmmeter. The calibration curve obtained by this method is displayed in Figure 3.7.

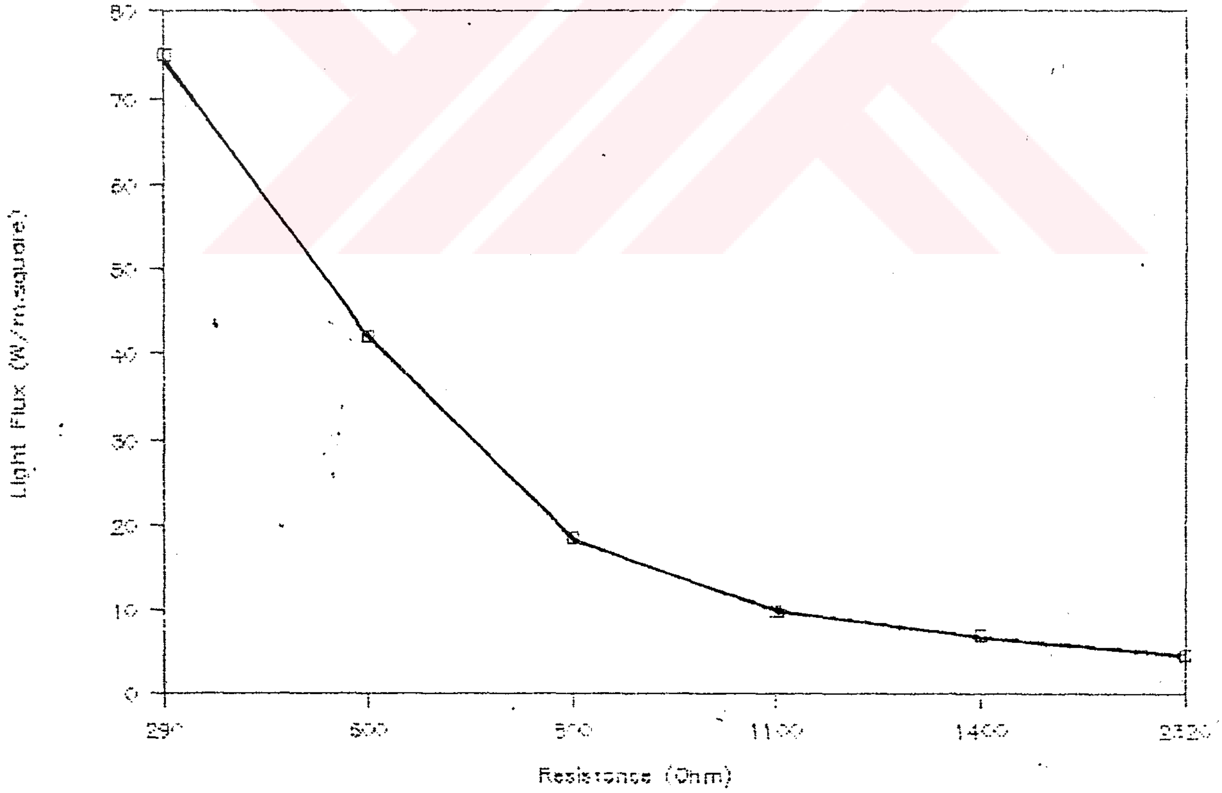


Figure 3.7 Light flux sensor calibration curve.

3.6 Actuators

Actuators were designed to keep the greenhouse variables close to the set points. When a variable sensed as to go out of the set point related controller is actuated by the MPU and required action takes place to bring the variable into tolerable range.

Actuators were used either directly (ventilator flap motor direction and pulse) or through relays and drivers connected to the PIA of the sensor-controller interface. Connection of the actuators were done according to the scheme shown on the Fig.3.8.

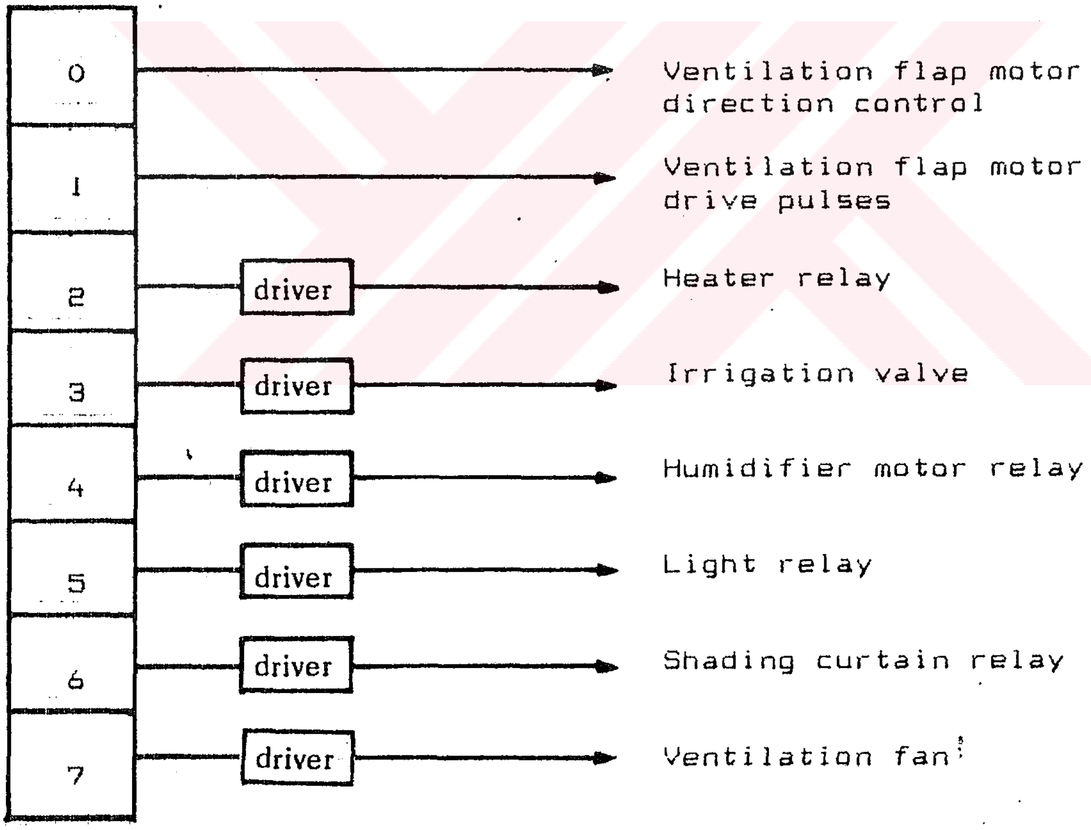


Figure 3.8 Controller-PIA connection diagram.

3.6.1 Ventilator

The ventilator has two flaps which are coupled mechanically to a stepper motor, and a fan. Stepper motor allows the flaps to be opened at desired angles. Opening angle is set externally by user, considering the outdoor temperature and the wind speed. In the system flaps are opened and fan runs when the greenhouse temperature or the relative humidity exceeds the upper limit settings. They are closed when the temperature or relative humidity drops to normal level.

In industrial ventilation systems flaps are replaced by specialy designed window system located at the sides and the roof of greenhouse and the opening angle should be calculated automatically by control system according to inner and outer temperatures and wind speed.

3.6.1.1 Stepper Motor and Controller [3]

Stepper motors are motors which rotate at constant rotary angles while the condition of excitation is changed by input pulse signals to the stepper motor's windings. Feedback control is not required (i.e., the motor is an "open loop" configuration since the motor is controlled by the digital signal). The general characteristics of a stepper motor are:

■ The rotating angle of the motor is directly proportional to the number of input pulses per revolution. Typical step angles are 0.9^{o}, 1.8^{o}, and 3.6^{o}.

■ The angle error per step is very small and non accumulative. Values are usually 3-5 % in an unloaded condition.

- There is a rapid response to starting, stopping and reversing at input pulses below 1000 PPS.

- The stepper motor's inherent positioning ability allows it to be driven with a series of input pulse signals. This is an "open loop" system.

- Self-holding torque is a characteristic that allows a stepper motor's rotor to be held in a stopped position without the use of a brake. If the motor's windings are energized, this is called "holding torque". If the motor's windings are not energized it is called "detent torque".

- A wide range of rotating speeds (proportional to the input signal) are available.

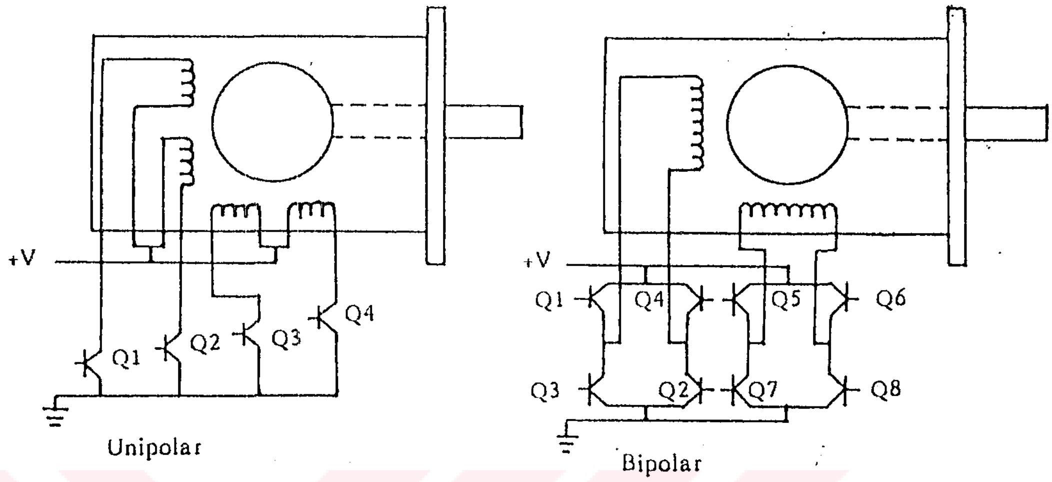
Stepper motors use two basic drive configurations:

- Unipolar.
- Bipolar.

The unipolar drive utilizes up to 50% of the motor's windings and does not reverse the direction of current flow in the windings.

The bipolar drive utilizes 100% of the motor's windings by changing the direction of current flow through the motor's windings. Figure 3.9 shows stepper motor winding energization and driving schemes.

CONNECTION DIAGRAM



SWITCHING SEQENCE

1 PHASE EXCITATION

step	Q1	Q2	Q3	Q4
1	1	0	0	0
2	0	0	0	1
3	0	1	0	0
4	0	0	1	0
1	1	0	0	0

step	Q12	Q34	Q56	Q78
1	1	0	0	0
2	0	0	0	1
3	0	1	0	0
4	0	0	1	0
1	1	0	0	0

2 PHASE EXCITATION

1	1	0	1	0
2	1	0	0	1
3	0	1	0	1
4	0	1	1	0
1	1	0	1	0

1	1	0	1	0
2	1	0	0	1
3	0	1	0	1
4	0	1	1	0
1	1	0	1	0

HALF-STEP EXCITATION

1	1	0	1	0
2	1	0	0	0
3	1	0	0	1
4	0	0	0	1
5	0	1	0	1
6	0	1	0	0
7	0	1	1	0
8	0	0	1	0
1	1	0	1	0

1	1	0	1	0
2	1	0	0	0
3	1	0	0	1
4	0	0	0	1
5	0	1	0	1
6	0	1	0	0
7	0	1	1	0
8	0	0	1	0
1	1	0	1	0

CW ROTATION

CCW ROTATION

Figure 3.9 Stepper motor energization and driving schemes [3].

The circuit to satisfy the 1-phase excitation switching sequence has been designed by using an up/down BCD counter and some logic gates. Although the counter counts from 0 to 9 (BCD), or reverse order, it is forced to count only up to 3 by connecting "Clear" pin to "C" output (second most significant output bit), in this case when the output tends to be 4, making the "C" bit 1, all output bits are cleared ("C" and "D" are disabled) and thus count sequence is repeated 0,1,2,3,0,... continually. In order to satisfy the switching sequence we need some additional gates because output of the counter is not same as the truth table of the stepping sequence. Another logic circuit is required to rotate the motor shaft in clockwise (CW), and counterclockwise (CCW) directions. The truth table of the circuit and arising circuit are in Table 4, and Figure 3.10 respectively.

The stepping motor rotates 1.8° at each step, Hence, 200 pulses are required to complete one revolution. For the purpose of not to load the PIA of the sensor-controller interface the stepper motor is connected through a bipolar driving circuit which is shown in Figure 3.11.

R	B	A	Q_1 Q_2	Q_3 Q_4	Q_5 Q_6	Q_7 Q_8	
1	0	0	1	0	0	0	
1	0	1	0	0	0	1	CW
1	1	0	0	1	0	0	
1	1	1	0	0	1	0	
0	0	0	1	0	0	0	
0	0	1	0	0	1	0	CCW
0	1	0	0	1	0	0	
0	1	1	0	0	0	1	

Table 3 Truth table of control and direction circuit.

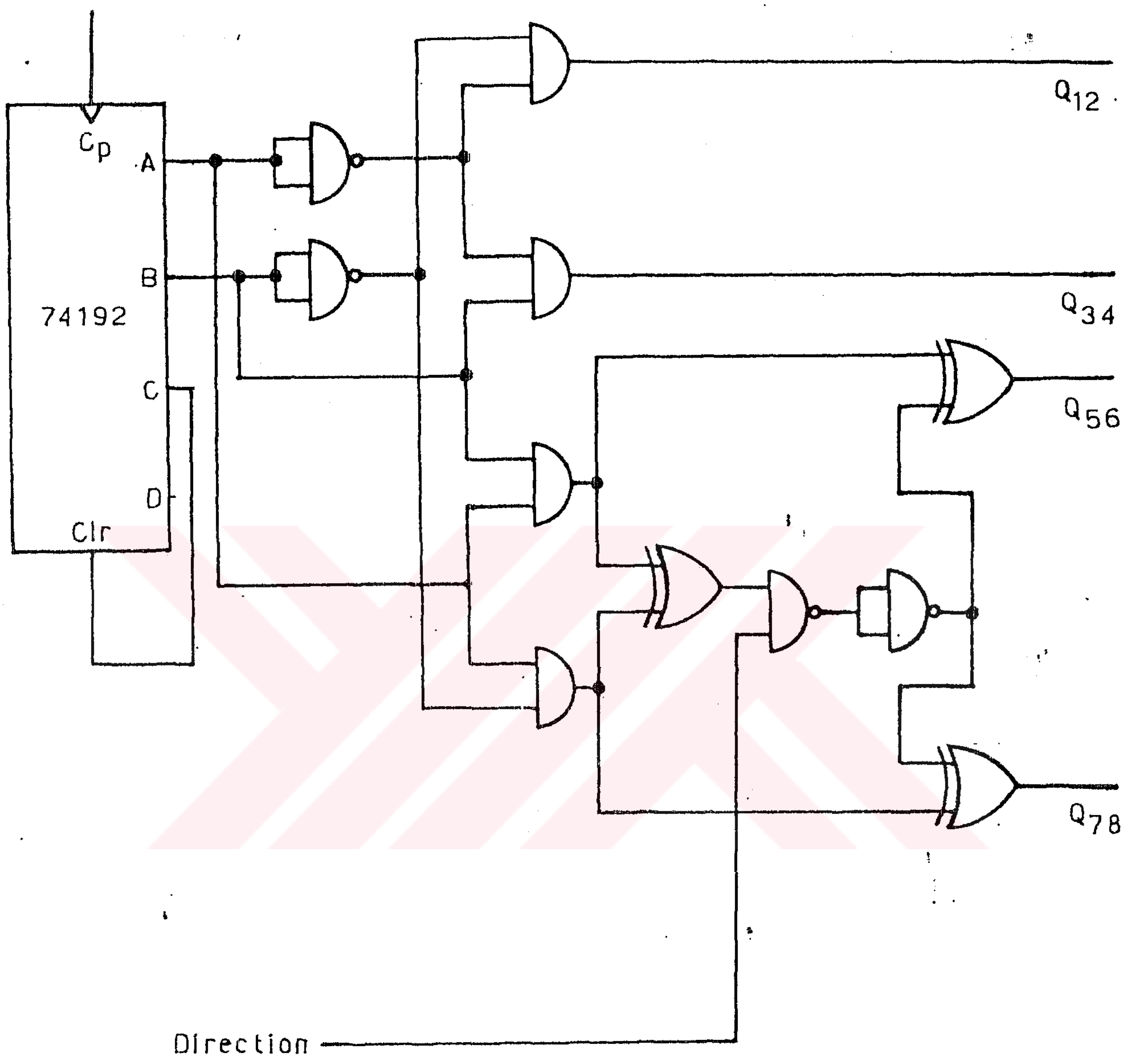


Figure 3.10 Control and direction circuit.

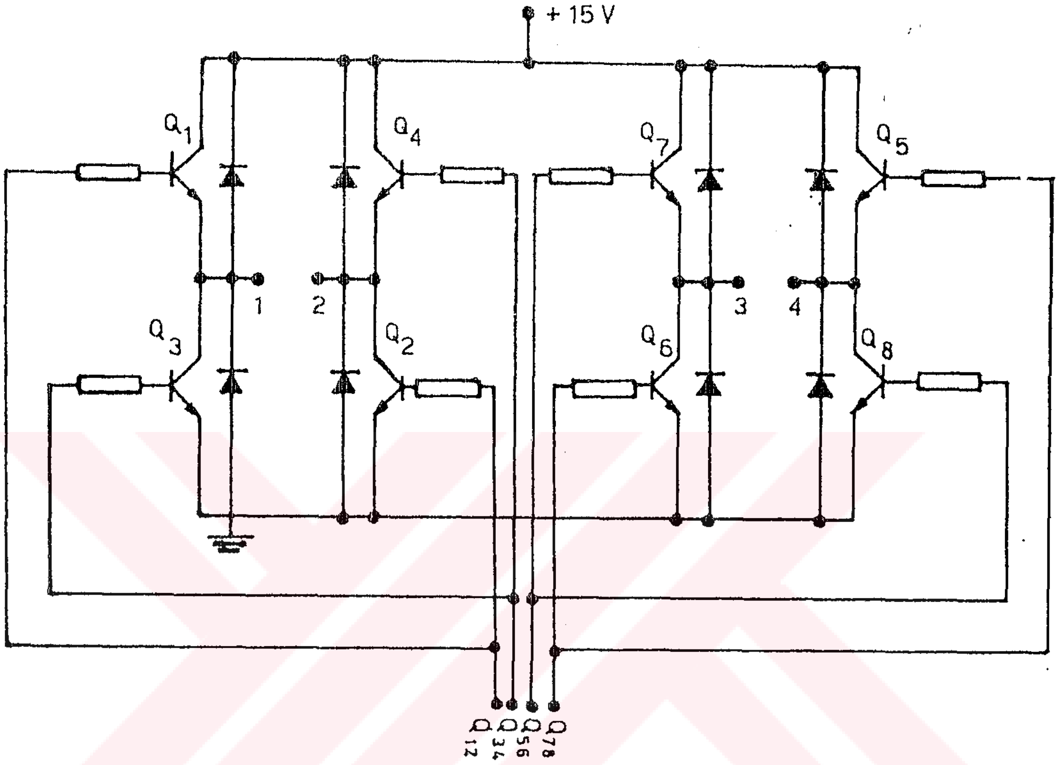


Figure 3.11 Bipolar stepper motor driving circuit.

Mechanical part of the air ventilation system consists of two metallic arms which open and close ventilation flaps connected to the stepper motor through a gearing system as shown in Figure 3.12. The length of arms and gear ratio are chosen in such a way that with lesser torque highest angle of rotation is obtained within range of angle settings.

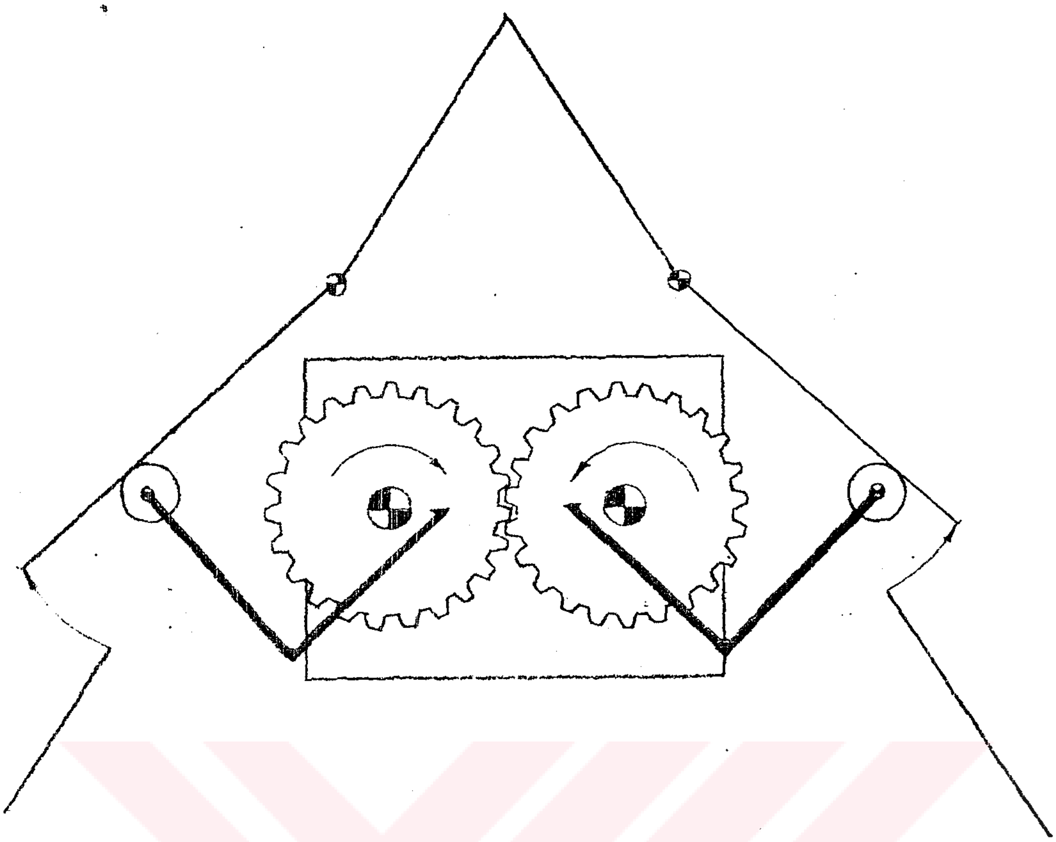


Figure 3.12 Mechanical part of the ventilator.

3.6.2 Hot Air Blower

Hot air blower is connected to the sensor-controller interface through a relay. When the inner temperature of the greenhouse drops under a set point ventilator flaps are closed (if they were open), the blower is turned on and remains in that position up to the temperature reaches to the set point, then the blower is turned off.

The blower operates with 220 V mains supply voltage. It is connected to sensor-controller interface through a relay. This connection provides isolation from the mains.

In practical greenhouses the blower is normally be replaced by conventional heaters such as fuel-oil or coal burning types to supply adequate heat according to the greenhouse size and local climate.

3.6.3 Irrigator

As stated in Section 2.3 irrigation plays an important role in plant growth. Among so many irrigation types the design of the present system was based on dipping watering scheme.

Irrigator consists of a solenoid valve, some ordinary plastic valves, and a plastic pipe (Figure 3.12). The solenoid valve is under the control of microprocessor unit which measures the soil moisture a few times in a second by means of a soil moisture sensor. If the moisture content of the soil drops under a set point the coil of the solenoid valve is energized then the valve opens allowing water to flow close to plant roots.

In order to provide a good irrigation a homogeneous watering is required. For this purpose water output of the solenoid valve was connected to a set of plastic pipes and so each was branched to supply equal amount of water at equal pressure to plants located in line. This irrigation system may also adoptable to raining type of irrigation but this would also cause to increase relative humidity in the greenhouse atmosphere. Hence dipping type of irrigation was found to be more efficient in the present design.

In the usual practice in greenhouses for one species more than one moisture sensor should be used to obtain a mean soil moisture. But if more than one species is to be grown in the same greenhouse different moisture sensors are needed to comply with different moisture requirements. In this case every piece of field containing the same type of plant should be considered as different as each has its own moisture sensors and solenoid valves. But latter forces the present design to be modified for two or more irrigation outputs and additional inputs for moisture sensors. Although input lines to the sensor-controller interface are adequate, the output lines are not. This situation forces us to use decoders at the output of the PIA dividing the eight outputs to maximum 2^7 new outputs, but this restricts the simultaneous operation of the actuators.

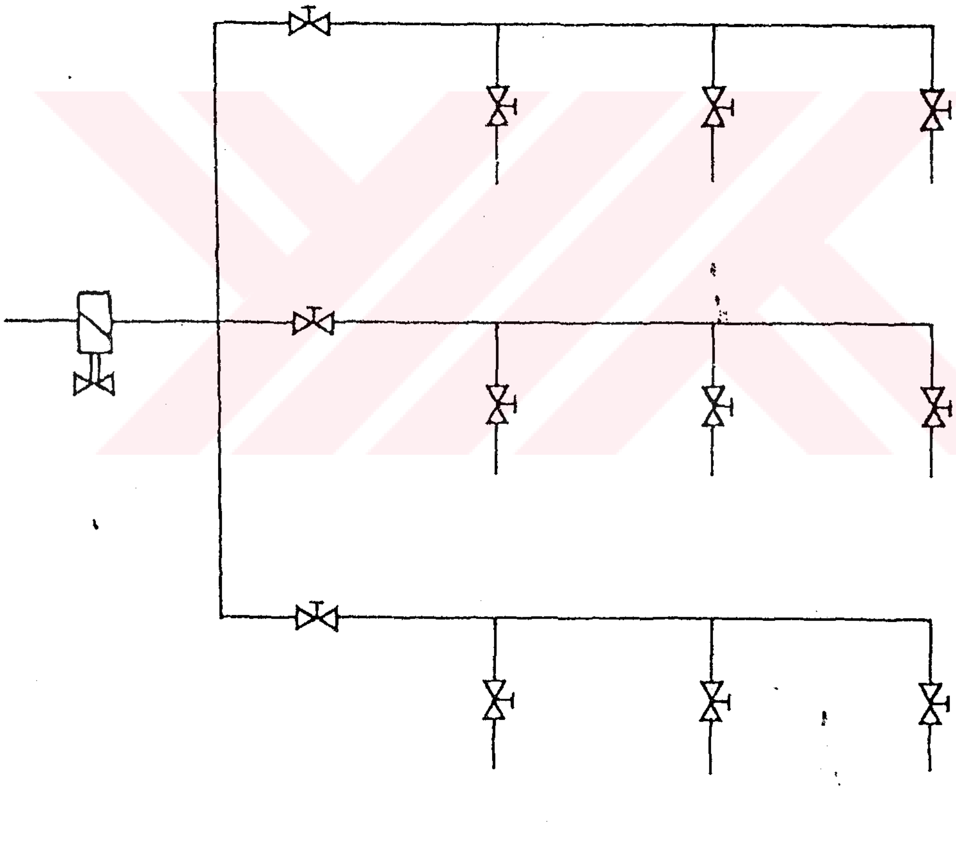


Figure 3.13 Irrigation system.

3.6.4 Humidifier

Another important greenhouse parameter is maintaining the relative humidity of the greenhouse atmosphere with the range required. This provides easy respiration of plants in the greenhouse.

Amount of relative humidity in a greenhouse atmosphere is proportional to amount of its vapor content and the relative humidity can be increased by increasing amount of vapor. To explain this enhancement let us boil some water in a container, but this causes at the same time to increase the temperature in the greenhouse, or if we leave some water in greenhouse waiting self vaporization in that case the temperature may not be enough to vaporize the water at required rate. The best way to increase the relative humidity is to spray water into the greenhouse since sprayed water vaporizes easily even at lower temperatures.

The humidifier system has a simple water pump operating at 12-15 V. d.c, and a length of plastic pipe having a spray nozzle at its end.

The water container that humidifier uses should be closed and be placed out of the greenhouse to avoid possible increase in relative humidity caused by the container.

3.6.5 Lighting System

To extend day-light exposure of a plant an artificial light source is included in the present design.

When the atmosphere illuminatin drops to a level below a set point artificial light sources must be turned on for a specified time duration.

The type of light source and the intensity must be chosen according to the type of plants to be grown and the size of greenhouse.

While selecting light sources the Table A2 will be useful. It lists types of light sources capable of supplying 1 lux (1 lm/m^2)of light flux corresponding to value in W/m^2.

This point should be considered carefully since on one hand the type of light source determines installation cost of the system and on the other hand the light source may increase temperature of greenhouse atmosphere.

To define the average flux for a given type of lamp in terms of the installed lamp wattage per unit of illuminated area, a lamp can be accepted as a point source and can be visualised to illuminate effectively a square area of which each side equal to twice the height of the lamp above the plants. A 400 watt lamp mounted 3 m above a plantation area would therefore be regarded as providing an installed capacity of 11 W/m^2. Clearly a given installed capacity can be provided both by a small number of large lamps or a larger number of small ones.

3.6.6 Shading Curtain

During summer times temperature of a greenhouse may increase to high levels due to direct radiation. In this case ventilation may not be enough to decrease the temperature additional shading curtain must be used to weaken radiation of the sun-shine.

The shading curtain is used to prevent the greenhouse temperature to increase above a set point during the day time. Because of handicaps of mechanical problems real shading is not installed, instead a LED is used to indicate on/off operation of the shading curtain.

CHAPTER 4 SYSTEMATICS OF THE OPERATION

4.1 Operational Procedure

Before running the main program a digital watch program which displays the time at the top right of the screen is loaded and the local time is set by user.Following this procedure the main program is automatically loaded in and execution begins.

At first the program initializes the internal and external PIA ports for input/output data transfers. Later the output port is set off to disable all controllers. After reading the saturated vapor pressure table which is used to calculate relative humidity, the main menu is displayed. At this instant the user should select either parameter settings or statistical data options. These options are performed by subroutines "SET" and "STATISTICS" respectively.

Subroutine "SET" displays the name of greenhouse parameters and waits for the user to set upper and lower limits of each parameter, and to input window opening angle of ventilator flaps.

Subroutine "STATISTICS" displays a menu which declares the greenhouse parameters to plot their graphs against time. For this menu user may select any variable to see its graph on the screen or may return to the main menu.

After presetting the value of each parameter the program begins to scan the sensors to measure their values for processing. The sequence of basic process performed in the main program is as follows.

First, temperature is measured. If it is above the upper limit then the subroutine "VENTILATOR" is referred: The subroutine turns the fan on and opens the ventilation flaps allowing cool air circulation. This subroutine also calls subroutine "PULSING" which sends pulses through the sensor-controller interface to run step motor coupled to the flaps.

If the temperature is below the lower limit then the heater is turned on.

If the temperature is between the upper and lower limits then the subroutine "BLOVENTOFF" is called to turn off the blower and ventilator.

Second, relative humidity is measured as explained at section 3.4.1.

If the relative humidity is below the lower limit then the humidifier motor is energized.

If the relative humidity is above the upper limit then the humidifier is disabled and the ventilator is activated.

Third, the soil moisture is checked by reading the voltage on the sensor and computing the corresponding soil moisture from the formula derived using the sensor calibration curve.

If the soil moisture is below the lower limit then the solenoid valve connected to water inlet is energized.

If the soil moisture is equal or above the upper limit then the valve is unenergized.

Finally the light flux is measured by reading the voltage across the sensor and computing the light flux using light sensor calibration curve.

If the light flux is below the lower limit then the lamp is turned on for a predetermined duration.

If the light flux and the temperature are above the upper limits then the shading curtain is activated and the lamp is turned off.

When the temperature drops to normal then the shading curtain is unactivated.

At each measurement the measured data is displayed on the screen and is checked if it is in tolerable range, which is to be chosen as ∓ 2 unit for each parameter. If the measured data is out of the range an audio alarm is sounded to inform the user to check for any possible trouble at the controllers.

At each five minutes variables scanned and time are restored into arrays for further statistical evaluation.

4.2 The Flowchart

The system operation described in section 4.1 is explained in steps given in the flowchart diagram shown in Fig. 4.1 (through the pages 38,39,40,41,42).

The menu section for subroutines "SET" and "STATISTICS" is leaded off at the decision point 'select' in the main program. The related details of each subroutine are given in Fig. 4.2 and Fig. 4.3 respectively.

The subroutine "SET" accepts flap angle, upper and lower limits of each parameter, and "STATISTICS" displays each parameter versus time.

The subroutines "VENTILATOR", "BLOVENTOFF", "PULSING", and "ALARM" are called at different points of the main program whenever the related controls are required.

The subroutine "VENTILATOR" (Fig. 4.4) activates fan motor and flap motor in association with temperature and humidity changes.

The subroutine "BLOVENTOFF" (Fig. 4.5) alters the states of heater and ventilator if they are ON position depending upon the temperature and relative humidity of the greenhouse temperature.

The subroutine "PULSING" (Fig. 4.6) acts as a pulse generator to drive step motor whenever is required.

The subroutine "ALARM" (Fig. 4.7) signals false operation if any limit set for a controller is surpassed.

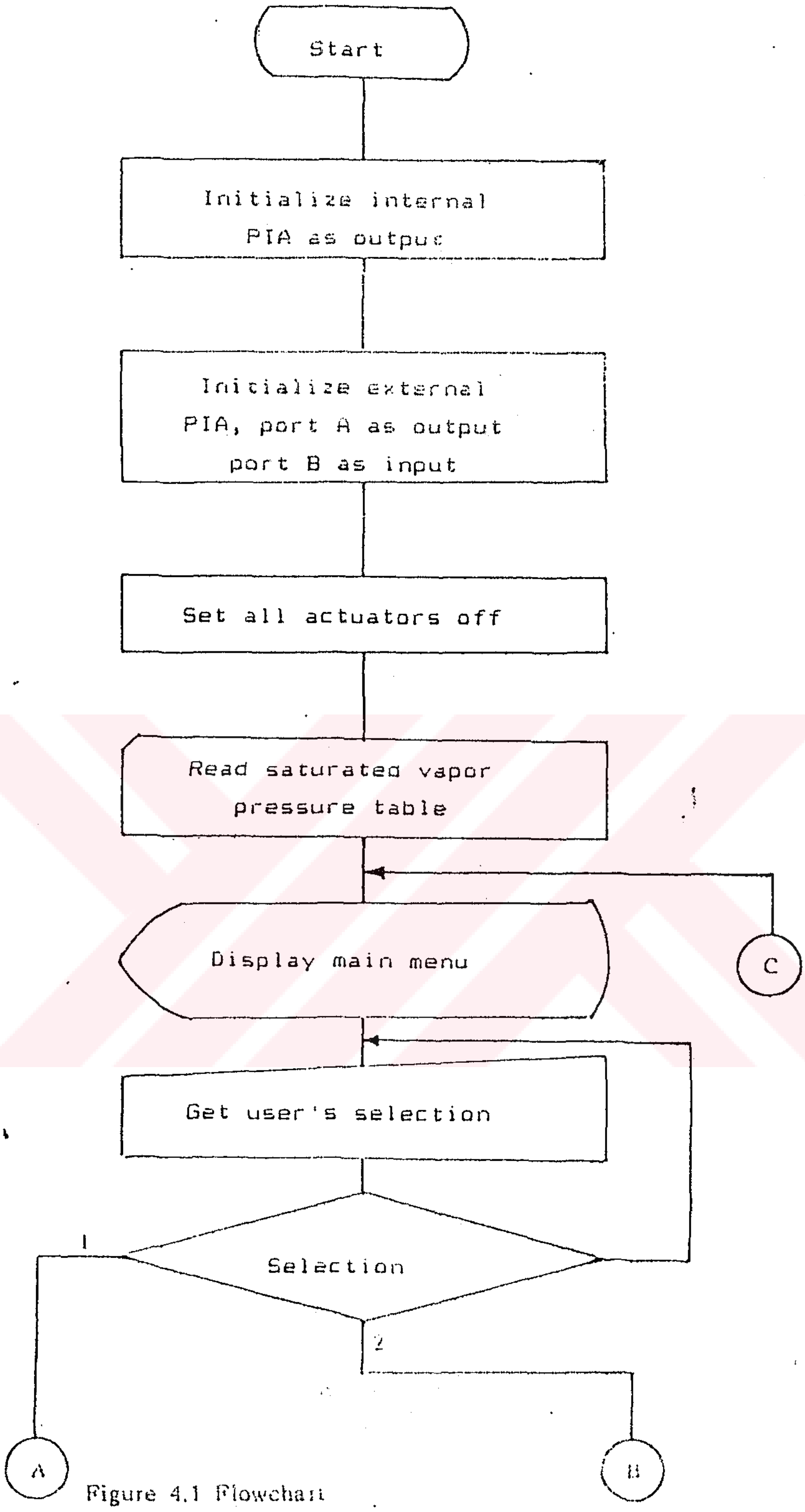
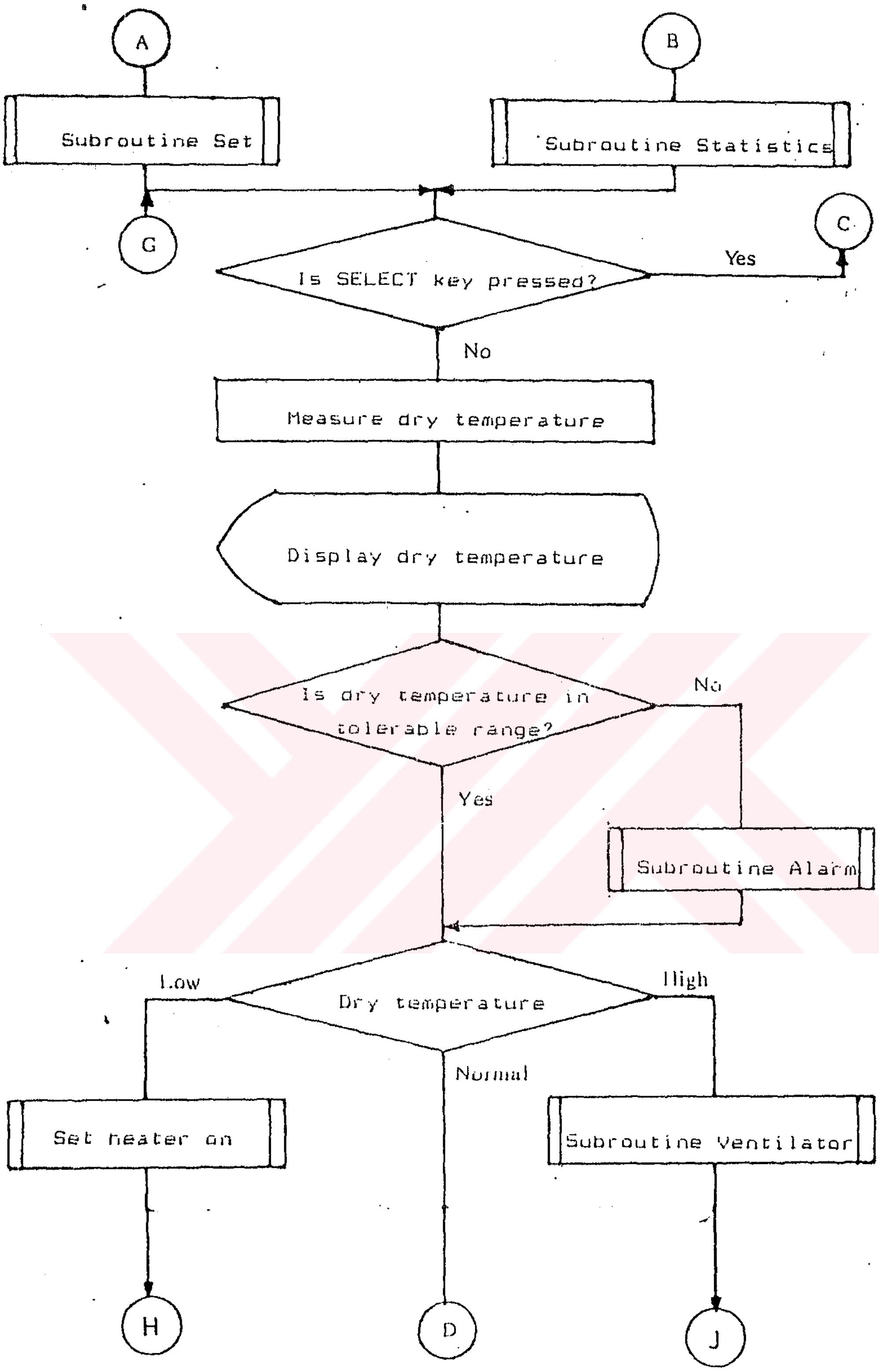
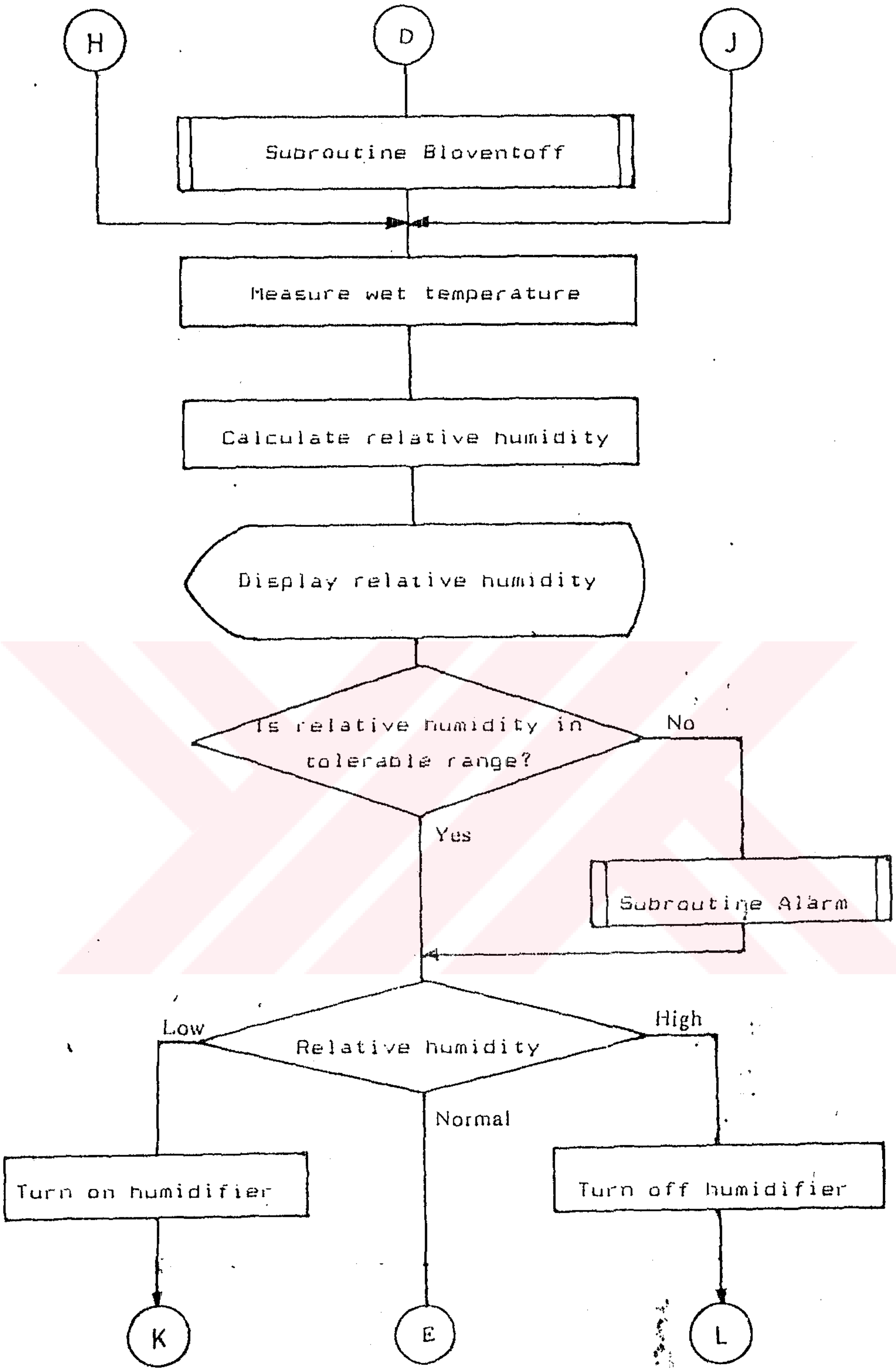
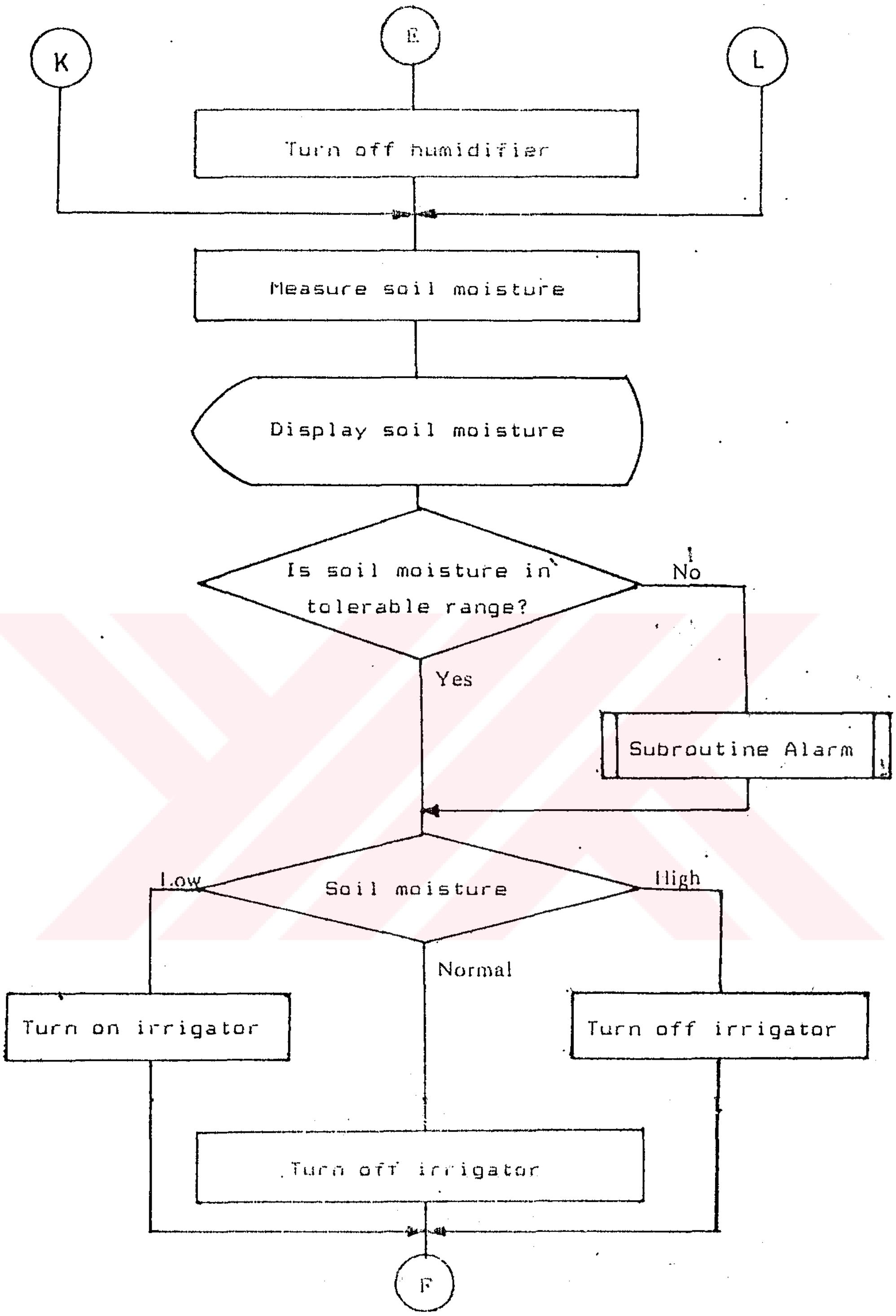


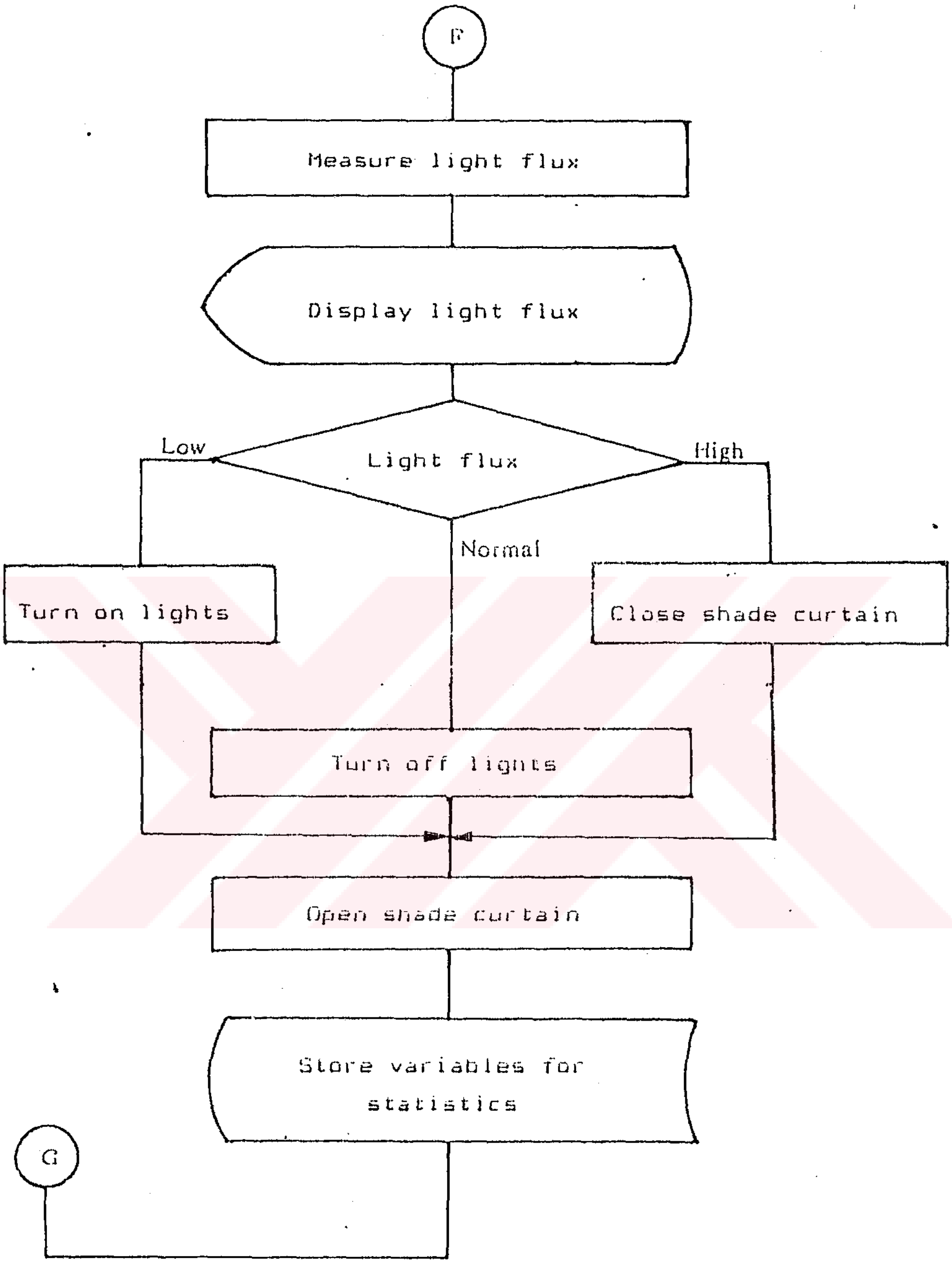
Figure 4.1 Flowchart

Figure 4.1 Flowchart


A
B
Subroutine Set
Subroutine Statistics
G
C
Is SELECT key pressed?
Yes
No
Measure dry temperature
Display dry temperature
Is dry temperature in tolerable range?
No
Yes
Subroutine Alarm
Low
Dry temperature
High
Normal
Set heater on
Subroutine Ventilator
H
D
J


H
D
J
Subroutine Bloventoff
Measure wet temperature
Calculate relative humidity
Display relative humidity
Is relative humidity in tolerable range?
No
Yes
Subroutine Alarm
Relative humidity
Low
High
Normal
Turn on humidifier
Turn off humidifier
K
E
L


K
E
L
Turn off humidifier
Measure soil moisture
Display soil moisture
Is soil moisture in tolerable range?
No
Yes
Subroutine Alarm
Soil moisture
Low
High
Normal
Turn on irrigator
Turn off irrigator
Turn off irrigator
F


F
Measure light flux
Display light flux
Light flux
Low
High
Normal
Turn on lights
Close shade curtain
Turn off lights
Open shade curtain
Store variables for statistics
G

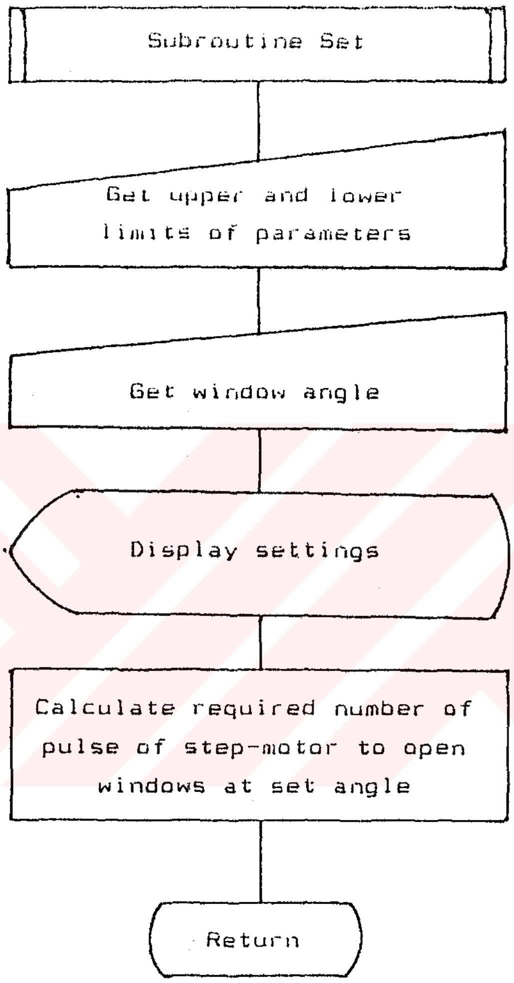


Figure 4.2 Subroutine SET

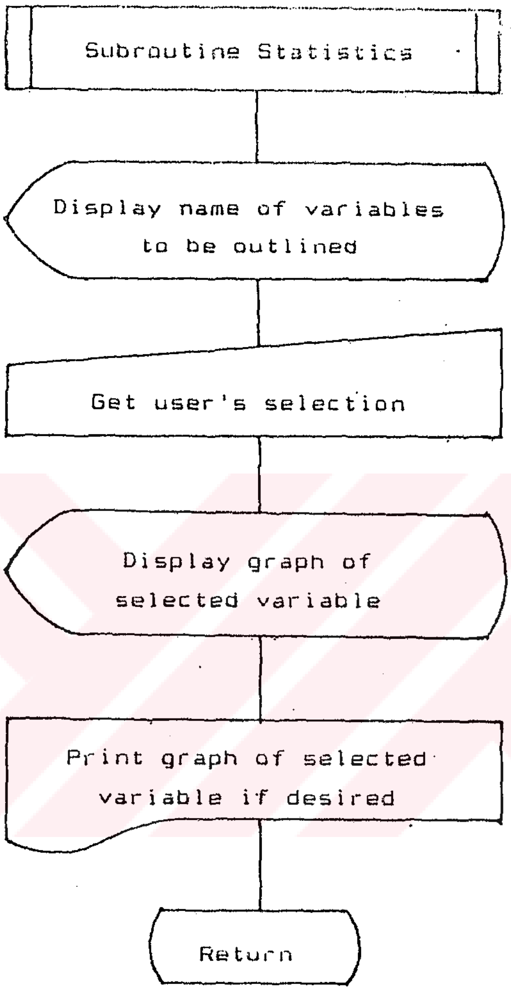


Figure 4.3 Subroutine STATISTICS

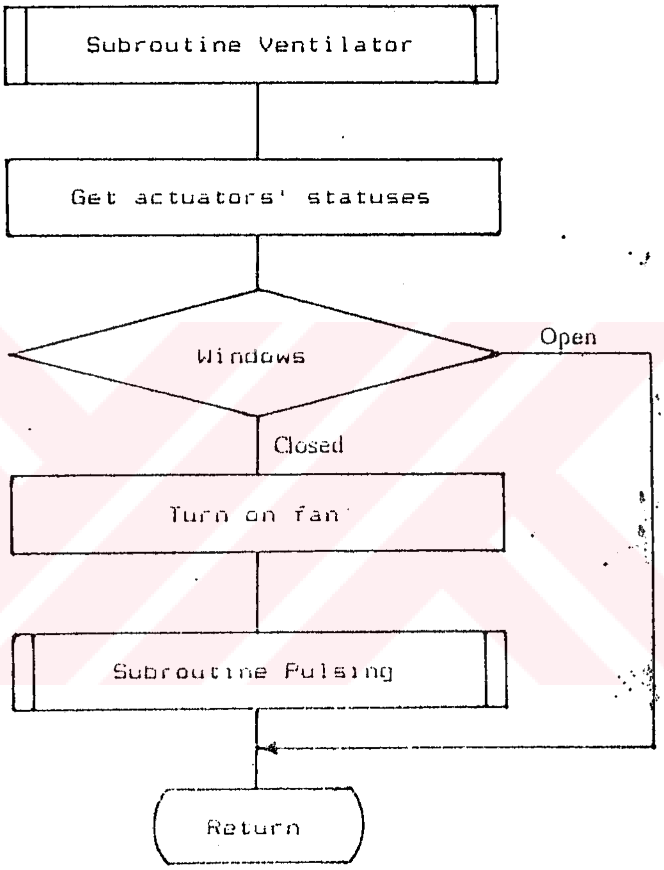


Figure 4.4 Subroutine VENTILATOR

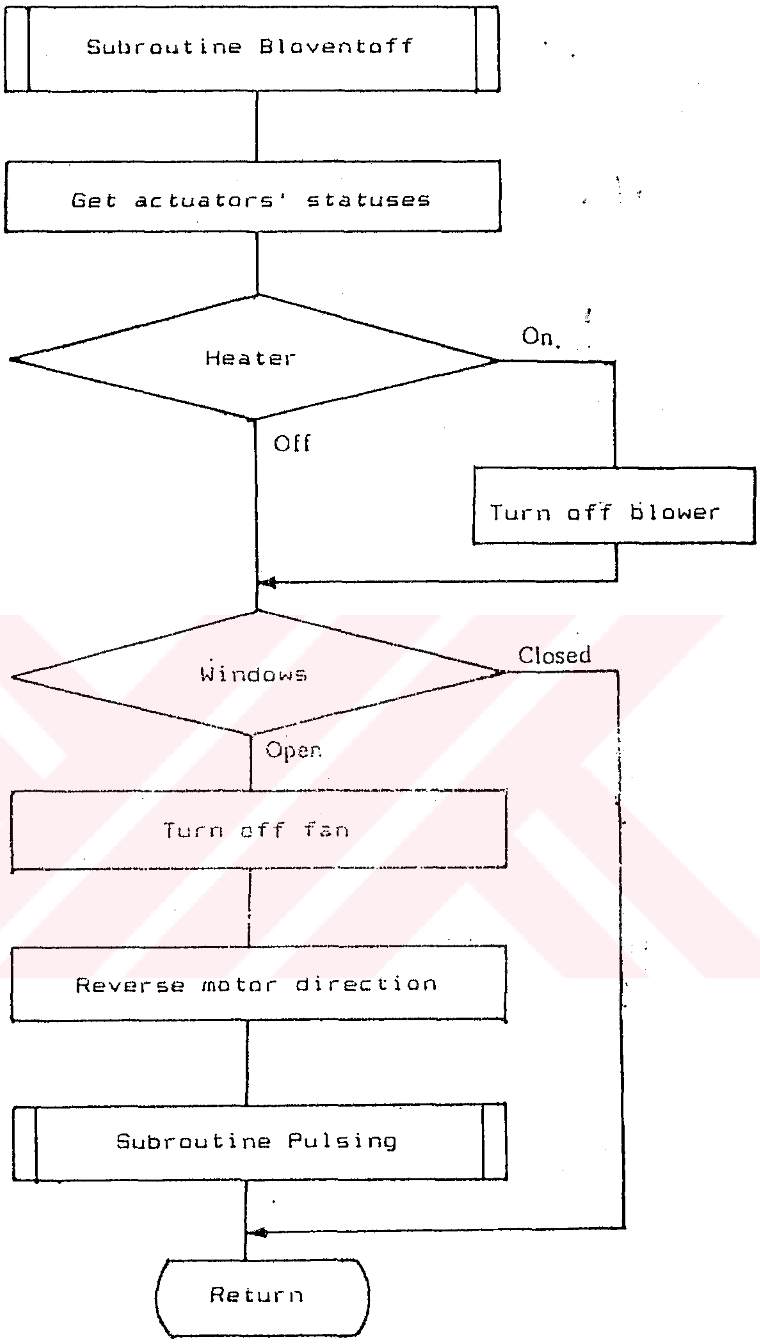


Figure 4.5 Subroutine BLOVENTOFF

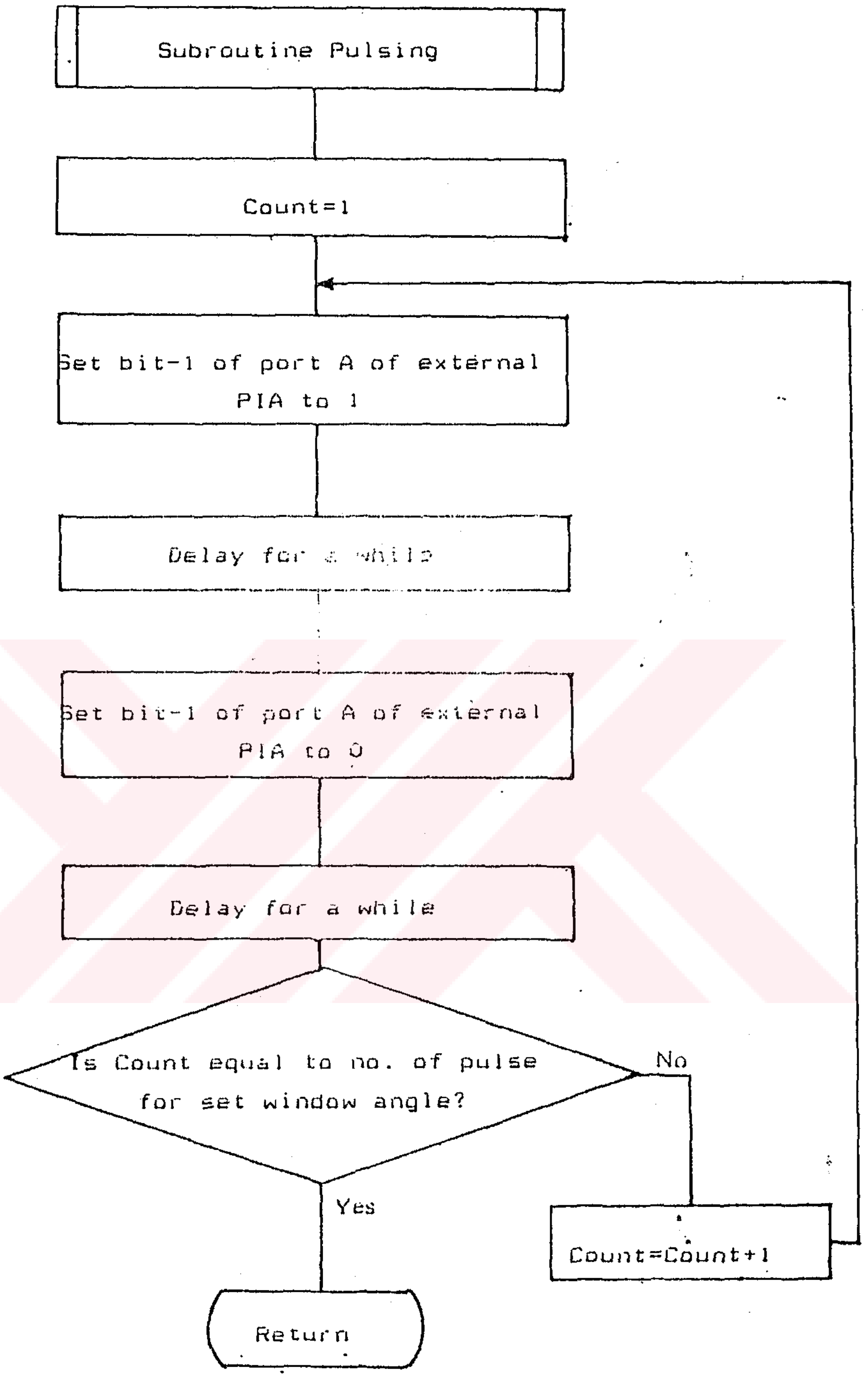


Figure 4.6 Subroutine PULSING

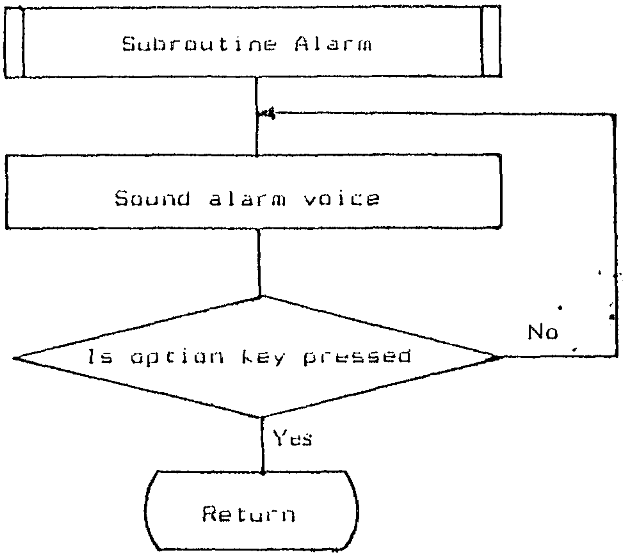


Figure 4.7 Subroutine ALARM

CHAPTER 5 DISCUSSION AND CONCLUSION

5.1 Discussion on Results

To asses the performance of the system designed the variations of relative humidity, soil moisture, temperature, and day-light were plotted over a 24-hour period. Also considering the dominance of temperature variations over other parameters data recording period of 24 hours was divided into two half-days. In the first-day recording was started at 12:38 during which the range temperature was set first in between 30-34 °C and, later, was maintained up to 18:18. Due to expected temperature fall during the night time, the second-day was started at 00:00 hours during which temperature range was adjusted in between 23-24 °C and longed up to 12:38 hours.

In Fig.5.1 24-hour variation of relative humidity is shown. Several dippings are distinctive features in this plot worth to comment. First noticable dipping occured at 07:20 hours and resulted from setting the temperature variations in a narrow band (23-24 °C) which may be causeed flap operation. A similar behaviour was also observed at the second part of the plot over which the variation during the initial hours of the first-day temperature rised above 34 °C, due to extra heating caused by direct sun-light infilitration into the greenhouse. This forced the control system to activate both flap and fan motors. Hence these two actions help relative humidity to fall in a short time period.

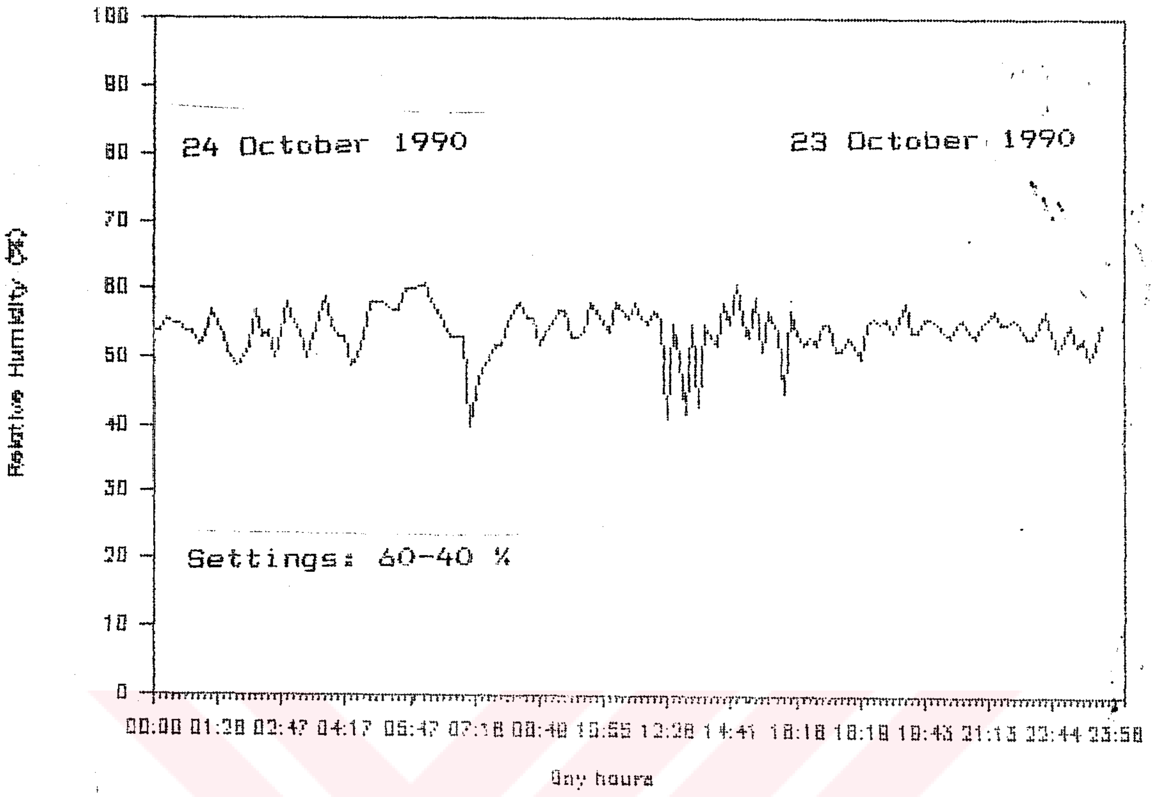


Figure 5.1 Variation of Relative Humidity over 24-Hour period

Figure 5.2 indicates the variation of soil moisture in two different half-days. The range defined for this parameter was 15-30 % over the 24-hour period. Since the soil temperature changes were small at the time of data recording (in late October) and at the same time burying the moisture sensor at a depth of 20 cm a flat variation was observed all along the 24-hour period. At around 18:18 hours a slight increase was resulted from a drop in the soil moisture below 15 % at which the irrigation system was activated. Thus expected moisture rise occured. An increase above 15 % was due to more water collection close to the sensor. Here, there was always possibility the moisture to increase above 30 %. Therefore there should be a balance between sensor depth and the range set for the soil moisture

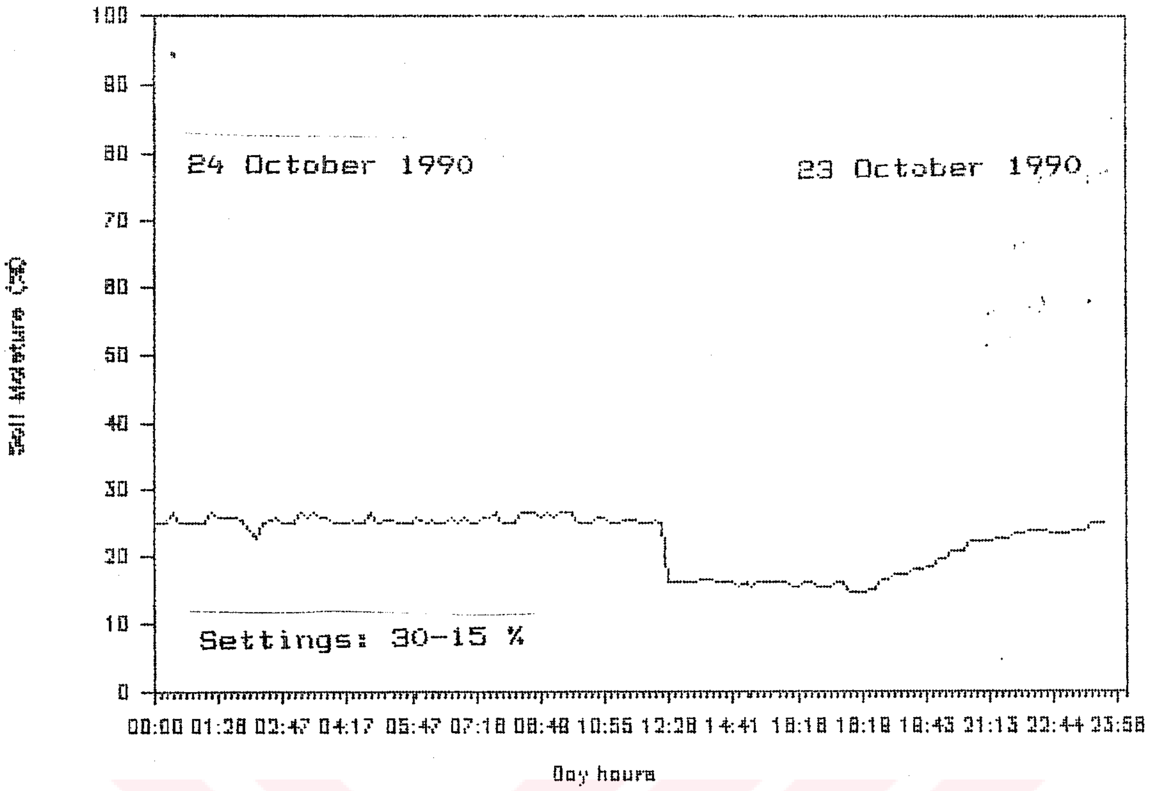


Figure 5.2 Soil moisture variation over 24-hour period.

In Fig.5.3 the temperature variation is shown for a 24-hour period. The changes observed stayed within the range of the settings throughout the period. As explained at the beginning of this section the levelling after 12:28 was caused from the change done on limitting the temperature range into 30-34 °C. The initial jump occured at about 12:30 hours was overcome by flap and fan operations. The temperature setting was changed to its previous values about 18:00 hours due to expected temperature fall during the night time.

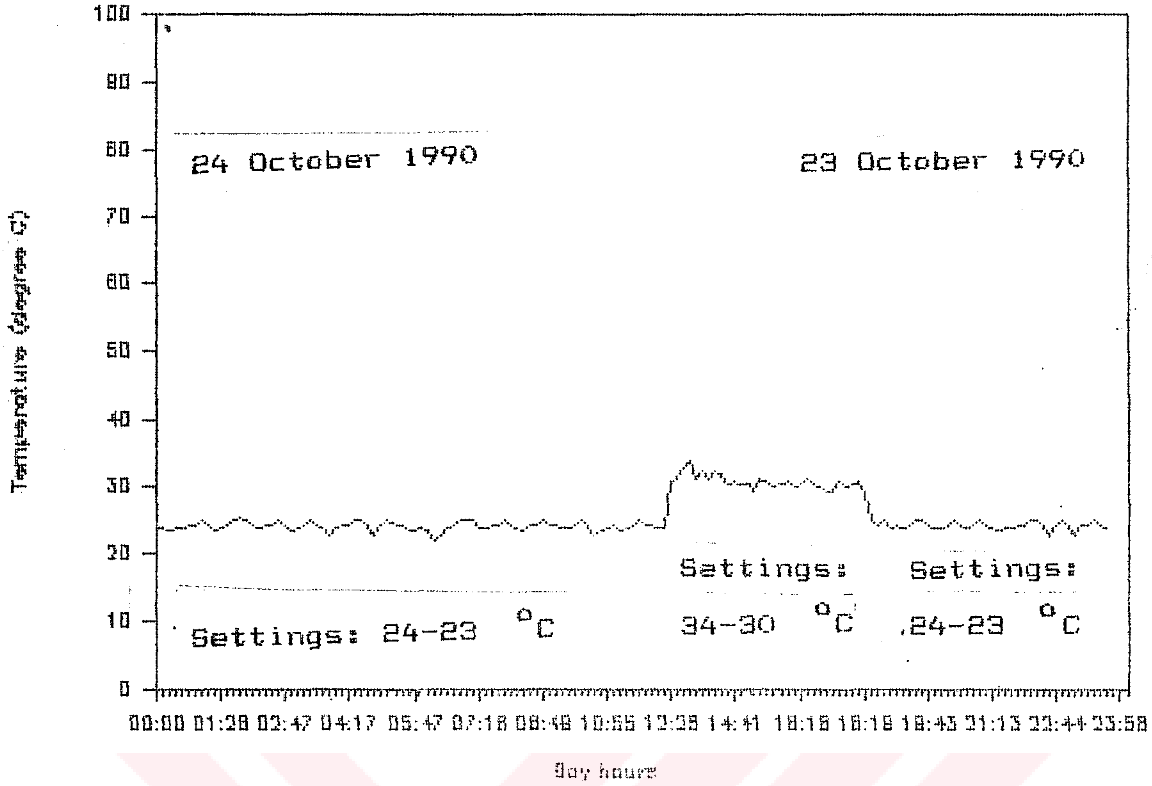


Figure 5.3 Temperature variation over 24-hour period.

To extend day-light exposure over a period of 18 hours a lighting control was included in the system. Although the output shown in Fig.5.4 follows the sun-light, the system switches on a single bulb (or a group of bulbs) when the light intensity drops below a lower limit defined for the darkness. Light flux measurement during the second half-day was obtained during a cloudy day giving rise to lowering in day-light flux. The sudden jump around 11:00 hours was due to appearance of the sun-light. In the present design, eventhough there is no start up point on this particular plot (Fig.5.4) signing switching the interior light(s), the night observations indicate operation was always ensured.

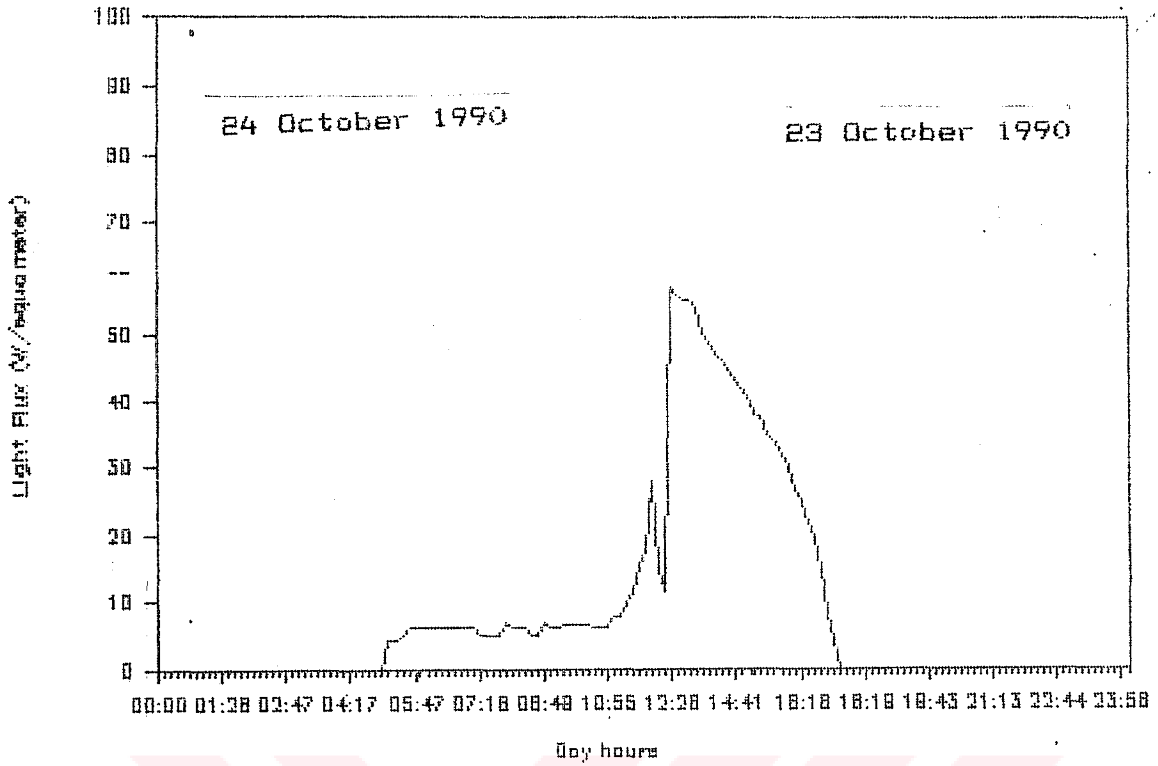


Figure 5.4 Day-light variation over 24-hour period

5.2 Conclusion

With the present automated system, by applying certain plantation rules the greenhouse soil and atmosphere may be kept in good conditions for a successfull plantation.

The parameters monitored vary within preset points during day and night periods as long as the open atmosphere temperature and relative humidity are tolerable to the present system.

Climatic control is also possible with the addition of an air-conditioner.

An important implementation of the present system seems to be the feasibility of monitoring greenhouse conditioning for enough number of parameters using a low-cost, 8-bit microcomputer.

5.3 Suggestions for Future Works

In the present design all those facilities obtainable from an 8-bit low-cost microcomputer were forced to its atmost. All 16 bits of two ports were used up fully to monitor temperature, relative humidity, soil moisture, and sun-light variations. For more elaborate control schemes involving extra parameters such as outside temperature, wind speed, CO_2 concentration, and light switching operation in a large-scale for multi-field greenhouse plantation, the use of a 16-bit two port microcomputer system would be suggestable.

REFERENCES

[1] Henry T. Northen, Rebecca T.Norten, "Greenhouse Gardening", The Ronald Press Company, New York, 1973, pp 21-27.

[2] A. E. Canham, "Artificial Light in Horticulture", Centrex Publishing Company, Eindhoven, 1966, pp 36-37.

[3] "Application of Integrated Circuits to Stepping Motor Drives", Oriental Motor U.S.A Corporation, 1987.

[4] "Acta Holticulturae", Symposium on High Technology in Protected Cultivation, Technical Communications of ISHS International Society for Horticultural Science, Hamamatsu, Japan, May 12-15, 1988.

[5] N. Baytorun, S. Onder, H. Koksal, "Tarimda Bilgisayar Kullanimi", Dunya Dergisi, October, 1989, pp. 29-31.

[6] B. B. Brey, "Microprocessor/Hardware Interfacing and Applications", Charles E. Merril Publishing Company, 1984.

[7] A. Tuzuner, "Alci Bloklarinin Calisma Prensipleri ve Kullanma Metodlari", T.C. Koy Isleri Bakanligi Topraksu Genel Mudurlugu, Toprak ve Gubre Arastirma Enstitusu Mudurlugu Yayinlari, Ankara, 1976.

[8] M. M. Mano, "Digital Design", Prentice/Hall International Inc., New Jersey, 1984.

APPENDIX

Saturated Vapor Pressure (mb)

T °C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	6.11	6.15	6.20	6.24	6.29	6.33	6.38	6.43	6.47	6.52
1	6.57	6.61	6.66	6.71	6.76	6.81	6.86	6.90	6.95	7.00
2	7.05	7.11	7.16	7.21	7.26	7.31	7.36	7.42	7.47	7.52
3	7.58	7.63	7.68	7.74	7.79	7.85	7.90	7.96	8.02	8.07
4	8.13	8.19	8.24	8.30	8.36	8.42	8.48	8.54	8.60	8.66
5	8.72	8.78	8.84	8.90	8.97	9.03	9.09	9.15	9.22	9.28
6	9.35	9.41	9.48	9.54	9.61	9.67	9.74	9.81	9.88	9.94
7	10.01	10.08	10.15	10.22	10.29	10.36	10.43	10.51	10.58	10.65
8	10.72	10.80	10.87	10.94	11.02	11.09	11.17	11.24	11.32	11.40
9	11.47	11.55	11.63	11.71	11.79	11.87	11.95	12.03	12.11	12.19
10	12.27	12.36	12.44	12.52	12.61	12.69	12.78	12.86	12.95	13.03
11	13.12	13.21	13.30	13.38	13.47	13.56	13.65	13.74	13.83	13.92
12	14.02	14.11	14.20	14.30	14.39	14.49	14.58	14.68	14.77	14.87
13	14.97	15.07	15.17	15.27	15.36	15.47	15.57	15.67	15.77	15.87
14	15.98	16.08	16.19	16.29	16.40	16.50	16.61	16.72	16.83	16.94
15	17.04	17.15	17.26	17.38	17.49	17.60	17.71	17.83	17.94	18.06
16	18.17	18.29	18.41	18.52	18.64	18.76	18.88	19.00	19.12	19.24
17	19.37	19.49	19.61	19.74	19.86	20.00	20.12	20.24	20.37	20.50
18	20.63	20.76	20.89	21.02	21.16	21.29	21.42	21.56	21.69	21.83
19	21.96	22.10	22.24	22.38	22.52	22.66	22.80	22.94	23.08	23.23
20	23.37	23.52	23.66	23.81	23.96	24.11	24.26	24.41	24.56	24.71
21	24.86	25.01	25.17	25.32	25.48	25.64	25.79	25.95	26.11	26.27
22	26.43	26.59	26.75	26.92	27.08	27.25	27.41	27.58	27.75	27.92
23	28.09	28.26	28.43	28.60	28.77	28.95	29.12	29.30	29.48	29.65
24	29.83	30.01	30.19	30.37	30.56	30.74	30.92	31.11	31.30	31.48
25	31.67	31.86	32.05	32.24	32.43	32.63	32.82	33.02	33.21	33.41
26	33.61	33.81	34.01	34.21	34.41	34.62	34.82	35.02	35.23	35.44
27	35.65	35.86	36.07	36.28	36.50	36.71	36.92	37.14	37.36	37.58
28	37.80	38.02	38.24	38.46	38.69	38.91	39.14	39.36	39.59	39.82
29	40.06	40.29	40.52	40.76	40.99	41.23	41.47	41.70	41.94	42.19

T °C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
30	42.43	42.67	42.92	43.17	43.41	43.66	43.91	44.16	44.42	44.67
31	44.93	45.18	45.44	45.70	45.96	46.22	46.49	46.75	47.02	47.28
32	47.55	47.82	48.09	48.36	48.64	48.91	49.19	49.47	49.75	50.02
33	50.31	50.59	50.87	51.16	51.45	51.74	52.03	52.32	52.61	52.90
34	53.20	53.50	53.80	54.10	54.40	54.70	55.00	55.31	55.62	55.93
35	56.24	56.55	56.86	57.18	57.49	57.81	58.13	58.45	58.77	59.10
36	59.42	59.75	60.08	60.41	60.74	61.07	61.41	61.74	62.08	62.42
37	62.76	63.10	63.45	63.80	64.14	64.49	64.84	65.20	65.55	65.91
38	66.26	66.62	66.98	67.35	67.71	68.08	68.45	68.82	69.19	69.56
39	69.93	70.31	70.69	71.07	71.45	71.83	72.22	72.60	72.99	73.38
40	73.78	74.17	74.57	74.97	75.36	75.77	76.17	76.58	76.98	77.39
41	77.80	78.22	78.63	79.05	79.46	79.88	80.31	80.73	81.16	81.58
42	82.02	82.45	82.88	83.32	83.75	84.19	84.64	85.08	85.52	85.97
43	86.42	86.88	87.33	87.78	88.24	88.70	89.16	89.63	90.10	90.56
44	91.03	91.51	91.98	92.46	92.94	93.42	93.90	94.39	94.87	95.36
45	95.86	96.36	96.84	97.34	97.84	98.35	98.85	99.36	99.87	100.38
46	100.89	101.41	101.93	102.45	102.97	103.50	104.03	104.56	105.09	105.62
47	106.16	106.70	107.24	107.78	108.33	108.88	109.43	109.98	110.54	111.10
48	111.66	112.22	112.79	113.36	113.93	114.50	115.07	115.65	116.23	116.81
49	117.40	117.99	118.58	119.17	119.77	120.37	120.97	121.57	122.18	122.79

Table A1 Saturated vapor pressure in mb.

Light source	Radiant flux in W/m^2 equivalent to	
	1 lm/ft^2	1 lux
Sun	43.2	4.00
Incandescent lamp 500W	44.9	4.16
Incandescent lamp 100W	45.7	4.23
Philips lamps: HPL 400W	37.6	3.48
ML 250W	37.6	3.47
HO 450W	26.7	2.47
TL-29 (warm white)	30.2	2.80
TL-32 (de luxe warm white)	39.3	3.64
TL-33 (white)	33.6	3.11
TL-34 (de luxe white)	39.0	3.61
TL-55 (daylight)	39.3	3.64
TL-15 (red)	158.6	14.68
Osram lamps:		
warm white	29.8	2.77
de luxe warm white	31.7	2.94
daylight	32.4	3.01
white	33.5	3.11
natural	37.3	3.47
colour matching	41.6	3.86
MA/V 400W	27.4	2.55
Neon 400W flood light	60.4	5.62
Special Magnesium arsenate	109.2	10.15

Table A2 Radiant flux conversion factors [4]