Predictive Control of a Simple H.V.A.C. System in a Test Hut

Ting-Hong Ngan

A Thesis

in

The Centre

for

Building Studies

Presented in Partial Fulfilment of the Requirements
for the Degree of Master of Engineering at
Concordia University
Montréal, Québec, Canada

March 1985

ABSTRACT

Predictive Control of a Simple
H.V.A.C. System in a
Test Hut

Ting-Hong Ngan

As a preliminary step towards cost effective predictive control of H.V.A.C. systems in commercial and institutional buildings, a minimal microcomputer (Apple II+) based monitoring and control system was developed. It is used to predict hourly ambient and room temperatures for a test hut 24 hours in advance, and to control the operation of an air conditioner, a baseboard heater, and a fan used to blow outside air into the hut so as to precool or preheat the mass of the hut, within the comfort zone (18 °C to 24 °C) according to calculations designed to minimize the use of purchased energy. Preheating was done with a 150 W. light bulb, with the fan off. Only twelve hourly ambient and room temperature readings are required for the control calculations. For normal weather, the shape of the predicted ambient temperature curve is derived from a short Fourier series, with 3 constants derived from historical temperature records, changed every two weeks. The Fourier shape is

adjusted up or down to match the previous 24 hour average temperature. When measured ambient temperatures differ strongly from those previously predicted, the arrival of a weather front is indicated, and the H.V.A.C. control strategy is changed until a new normal ambient temperature pattern is established. Room temperatures were predicted with a simple one capacitor model for the thermal flows, using "as built" thermal parameters derived from measured room temperatures. During a six day trial in November 1984, the system worked well in every respect, preventing the use of the air conditioner altogether, despite the arrival of a weather front at an awkward time.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to Dr. Marvin Shapiro, my thesis supervisor, for his guidance, support and meaningful suggestions throughout this work.

I would like to thank Concordia University and La Formation de Chercheurs et d'Action Concerteer (F.C.A.C.) for their financial support of this research in the form of graduate fellowships.

A special thanks to Joseph Zilkha for his technical assistance in the design, construction and use of the electronic equipment.

I appreciate the support and encouragement of my friends and colleagues who made valuable contributions throughout the duration of the writing.

And finally, a special thanks to my family for their patience and continuous support.

TABLE OF CONTENTS

	Page
Abstract	i
Acknowledgements	iii
Table of Contents	iv
List of Figures	vi
List of Tables	ix
Notation	xi
Chapter 1 Introduction	1
Chapter 2 Temperature Prediction Routine	
2.0 Introduction	12
2.1 Calculation of the Historic Daily Temperature Variation	16
2.2 Data Acquisition System	20
2.3 Comparison Between the Theoretical and Experimental Curves	47
2.4 Prediction Process	62
Chapter 3 Model for Thermal Flows in a Building	
3.0 Introduction	69
3.1 Calculation Model	72
3.1.1 Charging Mode (Mode 1)	80
3.1.2 Charging or Discharging Mode (Mode 2)	82
3.1.3 Discharging Mode (Mode 3)	84

Chapter 4 Experimental Apparatus and the Predictive Control program

4.0 Introduction 86

4.1 Experimental equipment 87

4.2 The on line control program 95

4.2.1 Initialization 97

4.2.2 Prediction 98

4.2.3 Normal Control 99

4.2.4 Abnormal Control 100

4.2.5 Time Control 101

Chapter 5 Results and Discussion

5.0 Introduction 104

5.1 Preliminary experiment to establish "as built" thermal parameters for the test hut 107

5.2 The on line predictive control experiment . 115

5.3 Conclusions 123

5.4 Recommendations for Further Studies 125

References 129

Appendix A 133

Appendix B 139

Appendix C 148

Appendix D 153

Appendix E 163

Appendix F 189

LIST OF FIGURES

Figure | Page

Figure		Page
2.1	Daily temperature variation for Montreal ..	18
2.2	Temperature variation with weather data for January	21
2.3	Temperature variation with weather data for February	22
2.4	Temperature variation with weather data for March	23
2.5	Temperature variation with weather data for April	24
2.6	Temperature variation with weather data for May	25
2.7	Temperature variation with weather data for June	26
2.8	Temperature variation with weather data for July	27
2.9	Temperature variation with weather data for August	28
2.10	Temperature variation with weather data for September	29
2.11	Temperature variation with weather data for October	30
2.12	Temperature variation with weather data for November	31
2.13	Temperature variation with weather data for December	32
2.14	Game Input/Output connector pinout	46
2.15	Comparison of historic curve and experimental weather data for 19th October, 1983	48

2.16 Comparison of historic curve and experimental weather data for 20th October, 1983 50

2.17 Comparison of historic curve and experimental weather data for 7th November, 1983 52

2.18 Comparison of historic curve and experimental weather data for 8th November, 1983 54

2.19 Comparison of historic curve and experimental weather data for 9th November, 1983 56

2.20 Comparison of historic curve and experimental weather data for 29th November, 1983 58

2.21 Comparison of improved historic curve and experimental weather data for 7th November 60

2.22 Comparison of improved historic curve and experimental weather data for 29th November 61

2.23 Temperature curves predicted from 21:00 Nov. 7 to 12:00 Nov. 8, 1983 64

2.24 Temperature curves predicted from 19:00 Nov. 8 to 6:00 Nov. 9, 1983 65

2.25 Temperature curves predicted from 11:00 to 20:00 Nov.9, 1983 66

3.1 Thermal flow diagram for an office 74

3.2 Electric circuit model for thermal flows in an office 75

3.3 Revised thermal circuit model for an office 79

4.1 Horizontal section through the test hut ... 88

4.2 Vertical section through the test hut 89

4.3 Vertical section through the external wall panel 90

4.4 Schematic of chart recorder 92

4.5 Cross section of fan 94

4.6 Cross section of mechanical controlled damper 94

5.1 Preliminary comparison between measured and predicted room temperatures 108

5.2 Comparison between measured and predicted room temperatures with adjusted R_{AL}, R_{LS}, R_C and C 109

5.3 Comparison between measured and predicted storage surface temperatures with adjusted R_{AL}, R_{LS}, R_C and C 110

5.4 Results from on line Predictive Control experiment and calculated curve for estimation of savings 116

5.5 Measured air temperatures at three different interior locations 121

LIST OF TABLES

Table		Page
2.1	Temperature variation curve fitting for January	33
2.2	Temperature variation curve fitting for February	34
2.3	Temperature variation curve fitting for March	35
2.4	Temperature variation curve fitting for April	36
2.5	Temperature variation curve fitting for May	37
2.6	Temperature variation curve fitting for June	38
2.7	Temperature variation curve fitting for July	39
2.8	Temperature variation curve fitting for August	40
2.9	Temperature variation curve fitting for September	41
2.10	Temperature variation curve fitting for October	42
2.11	Temperature variation curve fitting for November	43
2.12	Temperature variation curve fitting for December	44
2.13	Game I/O connector signal Descriptions	46
2.14	Temperature variation curve fitting for 19th October, 1983	49
2.15	Temperature variation curve fitting for 20th October, 1983	51

2.16 Temperature variation curve fitting for 7th November, 1983 53

2.17 Temperature variation curve fitting for 8th November, 1983 55

2.18 Temperature variation curve fitting for 9th November, 1983 57

2.19 Temperature variation curve fitting for 29th November, 1983 59

3.1 Electric circuit analogy to the thermal flows 73

x

Notation

A	An integration constant for the capacitor.
A_j	Area of jth glazing
B	$\sqrt{R_C*C*w1 + 1}$
C	Storage capacitance
C(1)	Average temperature of previous day
C(2), C(2)	Curvefitted Fourier coefficients from past weather data, changed every two weeks
I	Solar intensity
I1, I2, I3	Heat flow currents
IG	Internal heat gains + auxiliary heating
R_{AL}	Resistance between living space and ambient temperature
R_C	Bulk resistance for storage
R_{LS}	Surface resistance for storage
S1	Total solar energy penetrating all of the windows at solar noon
TA	Ambient Temperature
TR	Room temperature
TS	Temperature of storage surface
i	Incident angle for direct beam sunlight
t	Time
tsr	Sunrise time
tss	Sunset time
w	$2 * \pi/24$

wl	$\pi/(tsr-tss)$
α	Inverse of time constant
θ	Curvefitted phase angle from past weather data for Fourier series
ϕ_1	$TAN^{-1}[R_C*C*wl]$
ϕ_2	$TAN^{-1}[\frac{wl}{\alpha}]$
ϕ_3	$TAN^{-1}[\frac{\alpha}{w}]$
ϕ_4	$TAN^{-1}[\frac{\alpha}{2*w}]$
τ	Time constant = $C * (R_{AL}+R_{LS}+R_C)$
τ_j	Transmission of jth glazing

CHAPTER 1

INTRODUCTION

Normally, commercial office building heating and cooling system capacities are designed for the worst cases liable to occur at a particular location. The worst cases occur at most only a few days a year. For the majority of the year, the system is overdesigned and therefore inefficient. If a constant temperature at the middle of the comfort zone is to be maintained with an oversized system, we must either operate it in short bursts, or dump either hot or cool air to the outside, to balance the rate of heat or cooling generation with the load. If, however we allow the building temperature to fluctuate within the comfort zone (i.e. over a range of 5 or 6 °C) during occupied hours, we can not only make better use of the heating system, but, for most of the year can utilize fan cooling and internal heat gains to replace chiller cooling and purchased heat. This is done with Predictive Control by utilizing the thermal storage capacity in the mass of the building components, which can only be done when the internal temperature is allowed to fluctuate. Except when a weather front is passing through the locality, it is relatively easy to predict the fluctuations in ambient temperature for a 12 or 24 hour period. We know that the minimum ambient temperature will occur just before dawn, and the maximum at about 2 p.m. solar time. For each building, after a few months of observation, we can obtain two balance temperatures: BL, the ambient temperature below which heating is required to supplement internal heat gains when the building internal temperature, TR is at the centre of the comfort range, and BU, the ambient temperature where cooling is required when TR is at the centre of the comfort zone. Suppose at 10 a.m. one day we predict (with the aid of weather records in our computer and measurements of TA from midnight to 10 a.m.) that TA will rise above BU at 1 p.m., and remain above BU for two hours. Instead of maintaining TR constant, we turn on the fan at 10 a.m. and cool the building with outside air, say 2 °C toward the bottom of the comfort zone. The fan is shut off at noon or 12:30. Thereafter the internal heat gains warm the building, let's say to the top of the comfort zone at 3 p.m. The stored internal heat gains then carry the building through to the next morning, without purchased heat on many days of the year.

Should the building be below the comfort range at 8 a.m., perhaps because of a night setback, a further savings can be made with Predictive Control. Heating is delayed to the last possible time before the occupants arrive. The building air is then heated, at full power, to the middle of the comfort zone, as rapidly as possible. Because of its high thermal inertia, the building mass remains cool, and is heated by internal gains rather than purchased heat to reach the comfort zone over the next hour or two. The stored internal heat gains are recovered the next night, along with those used to heat the thermal mass to the top of the comfort zone in the afternoon. During much of the cooling season, the morning warm up can be done by circulating ambient air, rather than with the heating system, so the thermal mass can be cooled at night to be below the comfort range in the morning, ready to absorb internal heat gains, and prevent operation of the chiller for most or all of the day.

The essence of Predictive Control is then to predict up to 24 hours in advance when purchased heating or cooling will be required, and then if possible to store "free" heat or cool in advance to prevent the predicted purchase. The building temperature is varied over a 5 or 6 ^{o}C range (centered on a different temperature in winter than in summer) to miminize purchases of energy over the next 24 hours. In most climates it is not possible to operate without purchased energy every day of the year, but annual savings of 50 to 60% [11] should be possible for office buildings, because of the large internal gains available for pre-heating.

The requirements for the Predictive Control system are some sensors and controls integrated with a computer having the appropriate software. The computer must control the heating, cooling and ventilation systems. The minimum required sensors are ambient temperature and indoor temperature. In large, zoned buildings, a temperature sensor for each zone will be required. Solarimeters, pressure, wind and humidity sensors would be useful, but are not crucial. The software falls into three general categories. (i) A real time ambient temperature prediction routine, with a historical file, and an analysis of recent temperature trends, capable of differentiating normal days from those when a weather front is passing through. (ii) A building thermal inertia evaluator capable of utilizing sensor data to correct the calculated thermal inertia for "as built" anomalies. (iii) An operating system, with different strategies for the various conditions desired throughout the year, capable of predicting the variation of room temperature for 24 hours in advance when the heating or cooling appliances are operated. The set point for room temperature varies almost continuously, but it does not float, as it would with a thermostat with a wide deadband. When neither pre-heating or pre-cooling are required, room temperature is adjusted to the middle of the comfort zone.

For many days in the intermediate seasons, with normal controls, heating will be applied during the morning when ambient temperatures are low, while cooling is required in the afternoon, when ambient has risen. Often, the afternoon heat gain is about equal to the morning losses, so if all systems were off, no energy would be required to keep the average indoor temperature close to the static thermostat setting during occupied hours. Predictive Control goes further than simple inaction on those days. The building is kept closer to the middle of the comfort zone in the afternoon by creating a longer but smaller temperature drop in the morning with controlled ventilation (if appropriate).

In the winter season, a large part of the solar and internal heat gains are utilized with Predictive Control, to reduce fuel consumption. Temperature setbacks to reduce night heating requirements are inherent in Predictive Control. An extra advantage is that the setback is variable from day to day, and from hour to hour, which often gives extra savings. The exceptions are some days when sudden weather changes are in the wrong direction, (a cold front) so the setback strategy based on a predicted normal ambient temperature pattern is too large, increasing the heating required the next day. However, these are only a few days in the winter and have only a minor effect on the overall savings.

In the summer season "free cooling" is utilized at night as well as during occupied hours, reducing cooling energy consumption and often demand load charges.

In contrast to many other conservation techniques, the absolute savings from Predictive Control are enhanced by most other conservation techniques. Reduction of infiltration increases the savings possible with controlled predictive ventilation, by lowering the minimum ventilation achievable when ventilation increases energy usage, Increased insulation or glazing resistance increases the thermal inertia time constant, and the separation between the cooling and heating balance temperatures, so more time is available to store heat or cold in the available thermal mass, and it can be utilized over a longer period. Delamping reduces the internal heat gains that can be utilized in winter, but has a greater impact on the summer cooling requirements because the indoor outdoor temperature differences are much smaller in summer, in most climates. Anything that reduces the temperature differences between different zones of a building will enhance the savings with Predictive Control because the effective temperature band of operation will be widened. Complaints from the colder rooms limit the amount of pre-cooling possible, and complaints from the warmer rooms limit the amounts of pre-heating possible. As an example, judicious amounts of phase change storage in the corner and centre rooms can pay off handsomely with this extra leverage. Increasing the effective thermal inertia of a building by removing carpets or changing air flows to obtain some heat exchange with more of the structural mass of a building can help as well.

Predictive Control has already been used in a few large buildings [11]. However, the computers employed were very expensive minicomputers with large memory capacities. The programs used are proprietory, so we can only guess that their sophistication matches the computers used. The objective of this work was to develop and validate short programs and low cost monitoring and control systems suitable for Predictive Control with inexpensive microcomputers. When such systems are fully developed, they will allow the use of this technique in the majority of commercial buildings, with investments of only a few thousand dollars, rather than a few hundred thousand.

The development of a complete Predictive Control system suitable for use in large multizone buildings was not attempted in this initial effort. Rather, most of the crucial elements of the system were developed and validated in short experiments in a test hut. These include a subprogram to predict ambient temperature 24 hours in advance, on days when no weather front passes through, a program and hardware to monitor 9 temperatures and control a rudimentary 3 element H.V.A.C. system in the test hut, and a separate procedure to evaluate the "as built" thermal resistances and thermal capacity necessary to obtain a thermal inertia time constant for the test hut. This time constant is necessary to evaluate an expected room temperature variation 24 hours in advance during operation of the on line control program, so that, for instance, pre-cooling is limited to amounts that cannot cause the use of purchased heat the next night. Some elements of a complete Predictive Control system were left for later development. These include methods for evaluating the maximum possible solar input for 24 hours in advance, and reconciling separate strategies for pre-cooling, etc., in the cases of full sun, no sun or partial sun. Another element left for later development is the prediction of latent cooling loads on humid summer days. Since there were no occupants in the test hut during the experiments, and the ventilating fan flow could not be varied, a routine for insuring minimum ventilation has yet to be developed. Thus far, only on-off controls have been used. Routines for the control of metering valves will be added later. A routine for fast morning warmup was not developed here. No insurmountable problems are foreseen for any of these future additions. The time and budget available simply did not allow their development at this stage.

In order to validate those elements of the control system chosen for development here as directly as possible, and avoid some mathematical complications that might confuse the issues at hand, the test hut experiment was deliberately kept simpler than an experiment in an occupied building. Direct solar gains were suppressed by making the test hut windowless. Minimum fan ventilation was not supplied. The heating and cooling appliances had no modulating controls. They were either on at full power or off. The internal gains (supplied by a 150 Watt incandescent bulb) were kept constant 24 hours a day. The cavity surrounding 3 of the test room walls, the ceiling and floor was kept at a constant 20 °C 24 hours a day. (In fact this caused a slight complication, but one easily resolved). The test hut doors were never opened during the monitoring period. The goal was to show that the low cost methods adopted had practical potential, not to simulate fully the control of a real building. This task will be third stage of the overall research program.

The development and validation of a new, fast method to predict hourly ambient temperatures 24 hours in advance on days with normal weather is discussed in chapter 2. Three constants derived from historical weather records, and one derived from on site measurements of ambient temperature are substituted in a short Fourier series. The historical weather constants are changed every two weeks. This technique is also used to signal the arrival and departure of weather fronts, so that the on line control strategy for the H.V.A.C. system can be changed as required. In chapter 3, a simple one capacitor model for the thermal flows in a building is adapted for use in this problem. A new method providing closed solutions to predict the hourly room temperature 24 hours in advance is developed. These are necessary for proper execution of the on line Predictive Control program. The same model was used in an off line calculation of the "as built" effective resistances and thermal capacity (in terms of the one capacitor model) for the test hut. Unfortunately, closed solutions for this problem are not yet available. Instead, a least squares best fit procedure was used to select the four thermal parameters (3 R's and the C) used in the on line control calculations. To reduce the time required for the least squares search, an iterative technique using measured temperatures during inversion of the model equations was used to select starting values for the least squares variation of the four thermal parameters. This method gave calculated room temperatures that matched those measured in an auxiliary experiment (described in chapter 5) to well within the accuracy of the low cost thermometers used. Thus, it is quite sufficient for the purpose at hand, even though somewhat lacking in mathematical elegance. Chapter 4 contains descriptions of the test hut, of the hardware used for Data Acquistion and control of the H.V.A.C. system, and of the details of the on line Predictive Control program. The experimental results are presented and analyzed in chapter 5, which also contains conclusions and recommendations for further studies.

CHAPTER 2

TEMPERATURE PREDICTION ROUTINE

2.0 Introduction

Since the start of human civilization, weather prediction has been an important factor for men, particularly for farmers and sailors. The prediction process was crude, and sudden changes were not usually foreseen. Nowadays, with detailed weather records for several decades, and low cost micro-computers available, we can do better.

In this chapter we describe the development of a micro-computer program which is capable of forecasting hourly ambient temperatures 24 hours in advance for normal weather and of sensing the arrival of abnormal weather, using ambient temperatures measured on site for the 12 previous hours and three constants derived from historical weather data. In normal weather, the daily variation of ambient temperature is similar to the historical pattern, whatever the daily mean temperature. Abnormal weather occurs during a change of weather system:- i.e. the daily mean temperature changes suddenly. A weather front is the boundary between a high pressure system and a low pressure system. When a high pressure system arrives the temperature will drop rapidly and remain below the historical average temperature for several days. On the arrival of a low pressure system, the temperature rises slowly and the weather remains warmer than average for several days. Because of the possiblity of changes of weather systems, the program must be able to recognize both the arrival of a weather front and the establishment of a new normal pattern.

In the prediction routine, a distorted 24 hour sinusoid, based on a short Fourier series is used to match the 2 week average of the historical daily ambient temperature swing. The daily pattern obtained is then placed around a daily mean temperature derived from current mesurements and used in the on line control program. When the measured temperatures deviate strongly from the predicted ones for several hours, the computer switches to the abnormal weather subroutine, and a different H.V.A.C. control strategy is used.

The strategy for abnormal weather is simply to oppose the weather front, if possible by maintaining room temperature near the middle of the comfort zone. For a cold front, we store internal gains by allowing room temperature to rise a few degrees. Should that heat be required later, it is available. If it is not required, no great expense has been incurred. For a hot front, we use fan cooling, if possible, to evacuate more than the internal gains and cool the building a bit. There is a risk with each of these actions that overheating or overcooling will occur later, requiring extra expenditures with the H.V.A.C. system. Thus, the rate of heating or cooling should be modulated, both with the season and with the time of day. Since the weather front condition lasts only a few hours in most cases, "free" heating at 4 P.M. is unlikely to cause extra cooling expense, because we return to the normal weather strategy before midnight, with plenty of time to use free cooling. However, the use of "free" heat at 11 A.M. could lead to purchased cooling at 2 P.M., so a lower rate of heating is advisable in summer until the new average ambient temperature accompanying the colder system is available.

There are, of course, other ways to predict the weather. Cloud formation can be an advance indication of the weather for the next few days. In many ancient civilizations, people predicted weather by studying wind direction and by interpreting the form, the colour, and the composition of the clouds. This technique, passed on from generation to generation and from century to century, is reasonably reliable in many locations. Unfortunately, Montreal is not one of those locations.

Today, government weather bureau predictions are based on the global weather situation rather than local weather formations. To establish the global structure of weather patterns, readings from many stations and satellite cloud pictures are fed to computers. Weather records from the past decade or more are stored in tapes and disks and are used in the weather forecasting process. This process can be carried out either with probabilistic or non-probabilistic models [12]. With the probabilistic models, the most likely paths for the pressure systems are estimated. In the non-probabilistic models, a suitable mathematical function is matched to the weather data.

A new computer, CRAY, purchased by Environment Canada in 1984, is the most powerful computer used in weather forecasting in Canada. Currently, it can predict weather up to 3 days in advance and theoretically, to 100 hours ahead. The various items predicted by this computer include the maximum and minimum temperature for each day, dew point temperature, barometric pressure, wind speed and wind direction, precipitation and cloudiness index. The rental and maintenance cost of hardware and software for this system is around 10 million dollars each year [8]. An additional 8 millions dollars [8] of annual operating cost is needed.

The accuracy of weather forecasts turned out by CRAY is high. It is, however, too sophisticated for on line thermal control of commercial buildings. Furthermore, expensive local measuring instruments would be required to utilize CRAY's capabilities since local temperatures and wind regimes can vary significantly from the regional values, especially in downtown locations. A simplified system, which can provide a reasonably accurate weather prediction with only local mesurements, is a more practical solution. In addition, the CRAY system only predicts daily extreme temperatures. For optimal building H.V.A.C. control, we would like to update our control strategy hourly when abnormal weather occurs. With the present system, we can predict hourly ambient temperature changes using only a few low cost sensors and an Apple micro-computer, to within 1.5 degree Celsius, which is accurate enough for control purposes.

2.1 Calculation of the Historic Daily Temperature Variation

The daily temperature swing varies seasonally with the amount of sunshine available on the horizontal. In summer at Montreal, the mean daily range of temperature is about 15 degrees Celsius due to the longer days and high elevation of the sun. The shorter days and lower sun angle in December produce a lower mean range of about 5 degrees.

A summary of the monthly mean of the daily temperature variation for Montreal, using ten years of weather data is shown in Fig. 2.1 [5][9]. The twenty-four hour cycle is separated into three regions. The ends of the white region are the times for the daily minimun and maximum temperatures. The numbers shown above the white region are temperaure increases above the daily minimum, averaged over each one hour period, and rounded to 1 figure accuracy. The ends of the black region are the sunrise and sunset times. Here, the hourly numbers show the temperature decrease below the daily maximum. During the times shown as hatched regions, the sun is up, but low in the sky , so air temperatures are decreasing. This particular summary was obtained from Environment Canada [5][9], but a similar one could be calculated from weather tapes for any other location.

Although the table in Fig. 2.1 gives a good summary of temperature changes for an average day for each month, a functional equivalent was preferred, for ease of programming. Therefore, a Fourier series was fitted to the data for each month shown in Fig. 2.1. Since Environment Canada had rounded the data of Fig. 2.1, creating unrealistic plateaus of constant temperature for periods up to 4 hours, some of the temperatures were changed by fractional amounts (no more than $\pm$ 0.4 degree Celsius) to recreate smooth data curves. A curve-fit program, shown in Appendix A, was used to determine the coefficients of the

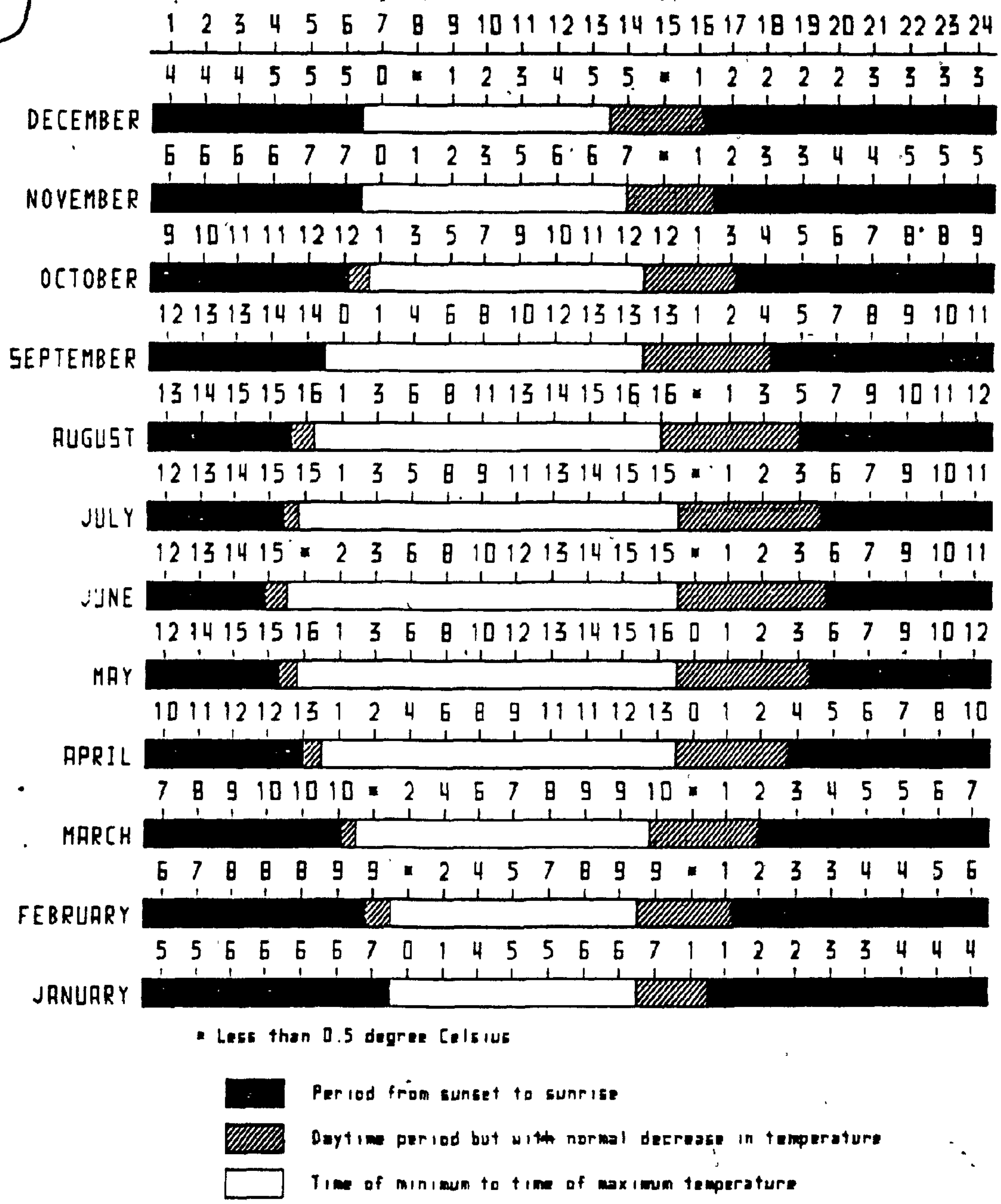


Figure 2.1 Daily temperature variation for Montreal

fundamental and the first and second overtones of the Fourier series. It was found that the second overtone did not improve the accuracy of the fit sufficiently to warrant its use. Thus, the equation used for the fits shown in Fig. 2.2 - 2.13 was the equivalent of:-

$$TA(t) = A(1) + A(2) * SIN(w*t) + A(3) * COS(w*t) + A(4) *SIN(2*w*t)+A(5)*COS(2*w*t) \quad (2.1)$$

Where TA(t) is the ambient temperature, and w is the angular frequency of the fundamental, $w = 2 * \pi / 24$ (rad./hr.)

In order to speed up the calculation, the cosine functions were replaced by two phase angles, θ_1 and θ_2, in the sine terms. Therefore, equation (2.1) becomes:-

$$TA(t) = C(1)+C(2)*SIN(w*t+\theta_1)+C(3)* SIN(2*w*t+\theta_2) \quad (2.2)$$

Where :

$$C(1) = A(1)$$

$$C(2) = \sqrt{A(2)^2 + A(3)^2}$$

$$C(3) = \sqrt{A(4)^2 + A(5)^2}$$

$$\theta_1 = TAN^{-1} [A(3)/A(2)]$$

$$\theta_2 = TAN^{-1} [A(5)/A(4)]$$

$$w = 2 * \pi / 24$$

$$t = Time$$

An analysis of the results showed that a simple relationship existed between the two phase angles calculated: θ_1 was always approximately 3 times θ_2. The synthetic curves obtained with $\theta_1 = 3*\theta_2$ were almost identical to the curves generated by fitting with equation (2.2). Thus equation (2.2) was further simplified to:-

$$TA(t) = C(1) + C(2) * SIN(w*t+3*\theta) + C(3) * SIN(2*w*t+\theta) \quad (2.3)$$

Where : $\theta = \theta_2$

Different constants C(1), C(2), C(3) and θ were determined for each month. The maximum absolute difference between the synthetic curves and the smoothed data (Figs. 2.2 - 2.13) derived from Fig. 2.1, and labelled Actual Y in Tables 2.1 - 2.12, is 1.1 degrees Celsius, which is well within recorded year to year weather differences. The prediction routine was checked against real temperatures recorded in 1983 to 1984, as will be discussed in section 2.3.

2.2 Data Acquisition System

Temperature data was collected with a system consisting of: a controllable switch to select any of 9 thermistor thermometers; a power supply for the thermistors; an amplifier; a voltmeter; and an Apple II+ computer equipped

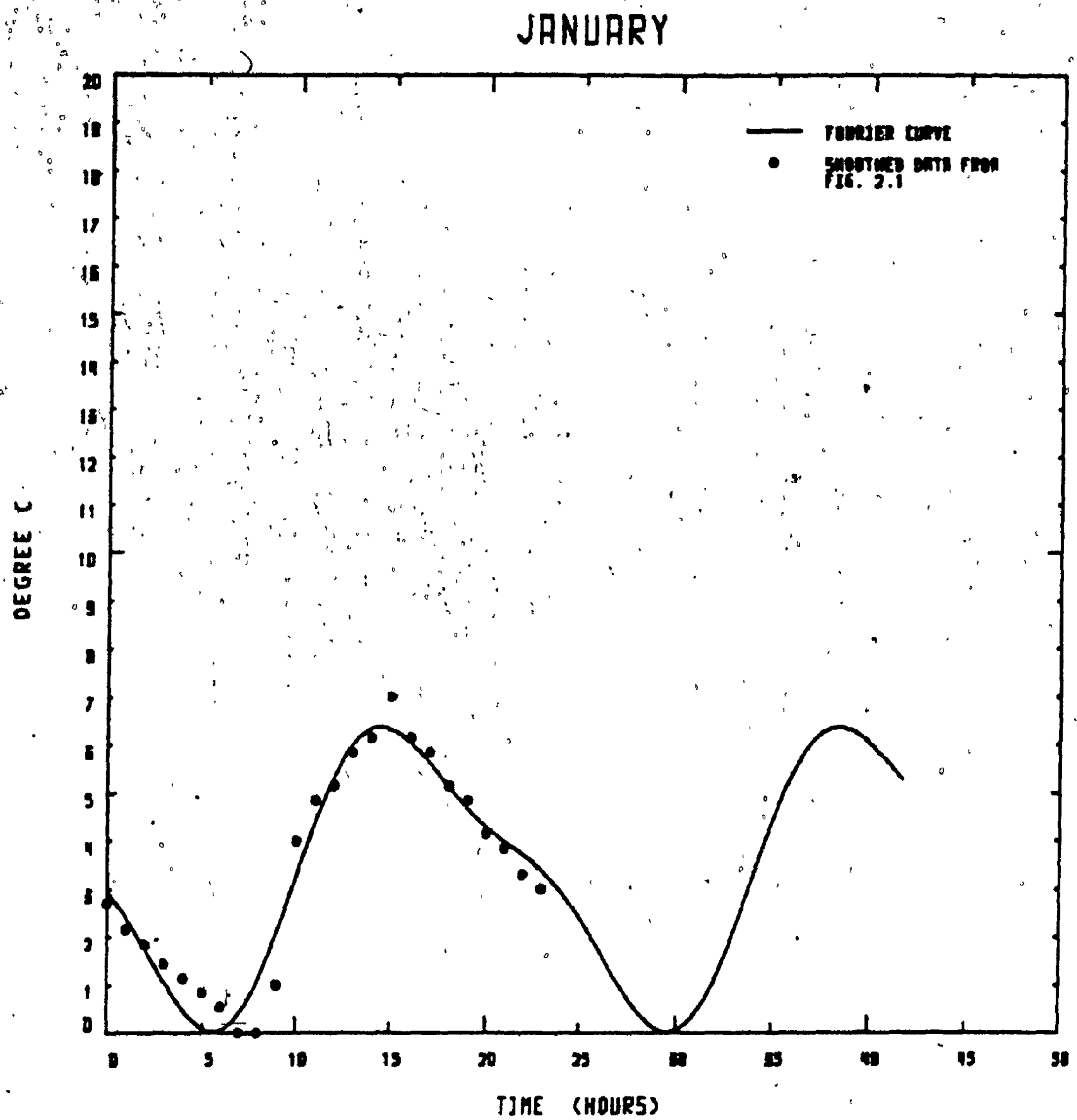


Figure 2.2 Temperature variation with weather data for January

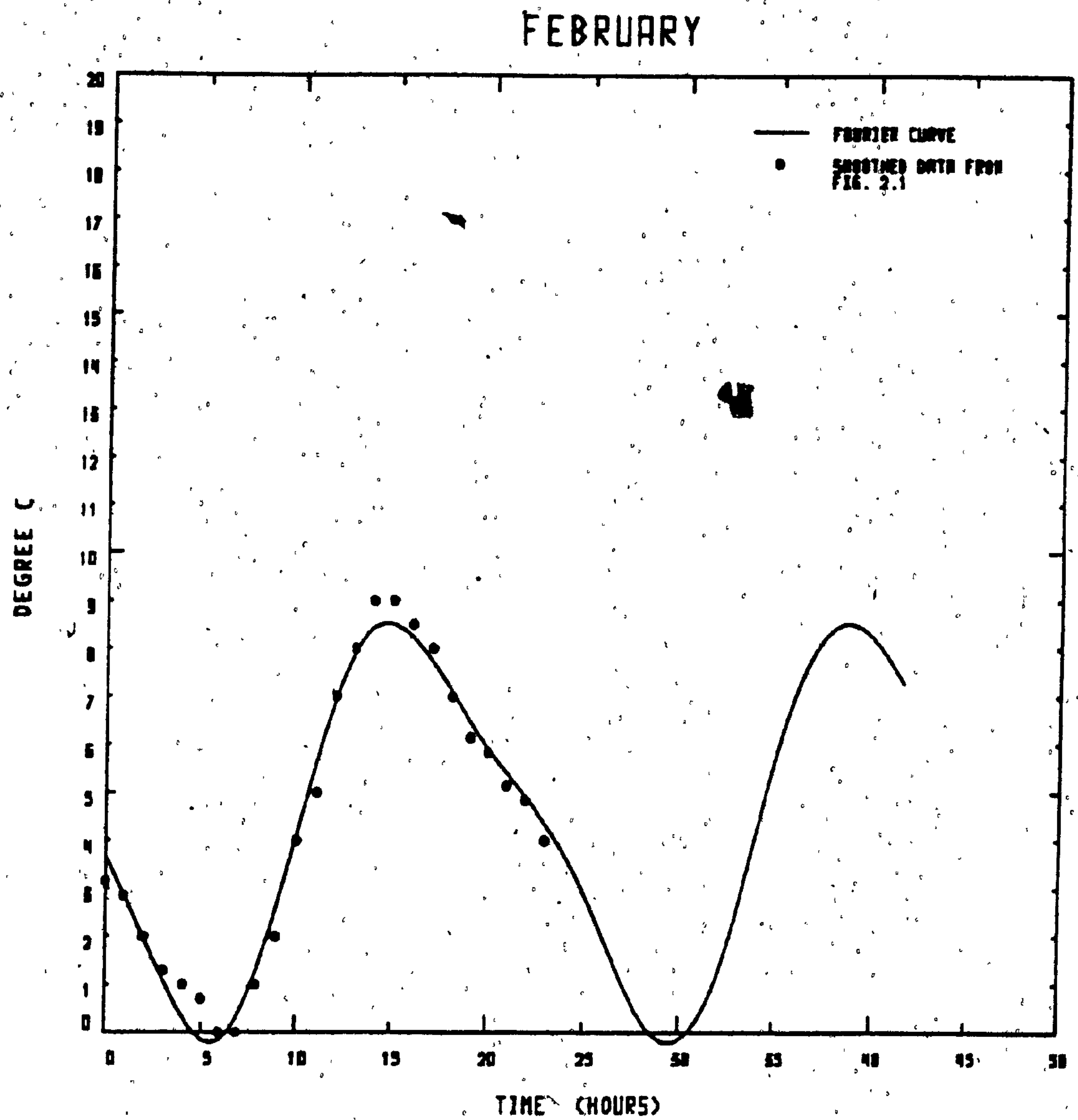


Figure 2.3 Temperature variation with weather data for February

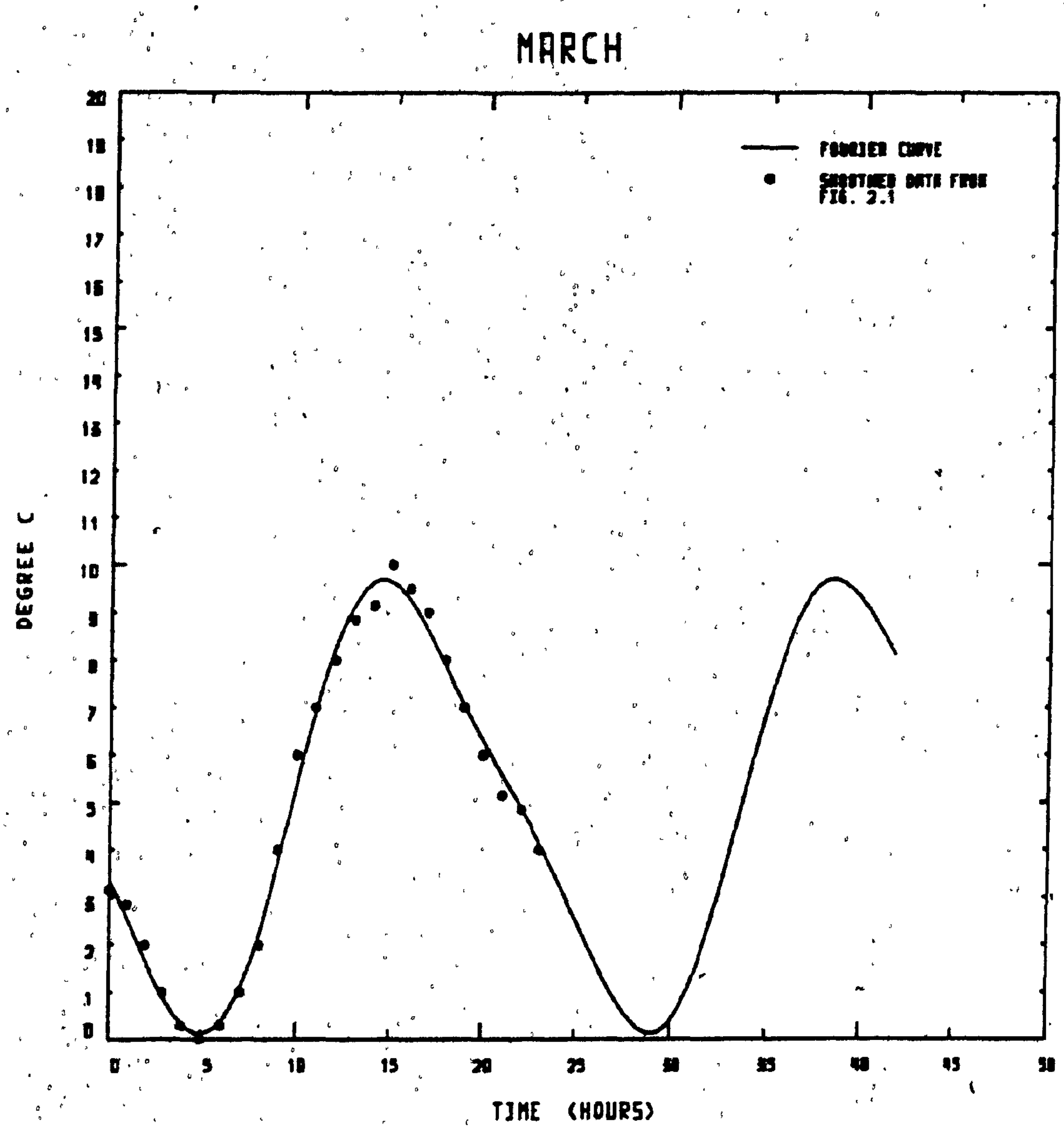


Figure 2.4 Temperature variation with weather data for March

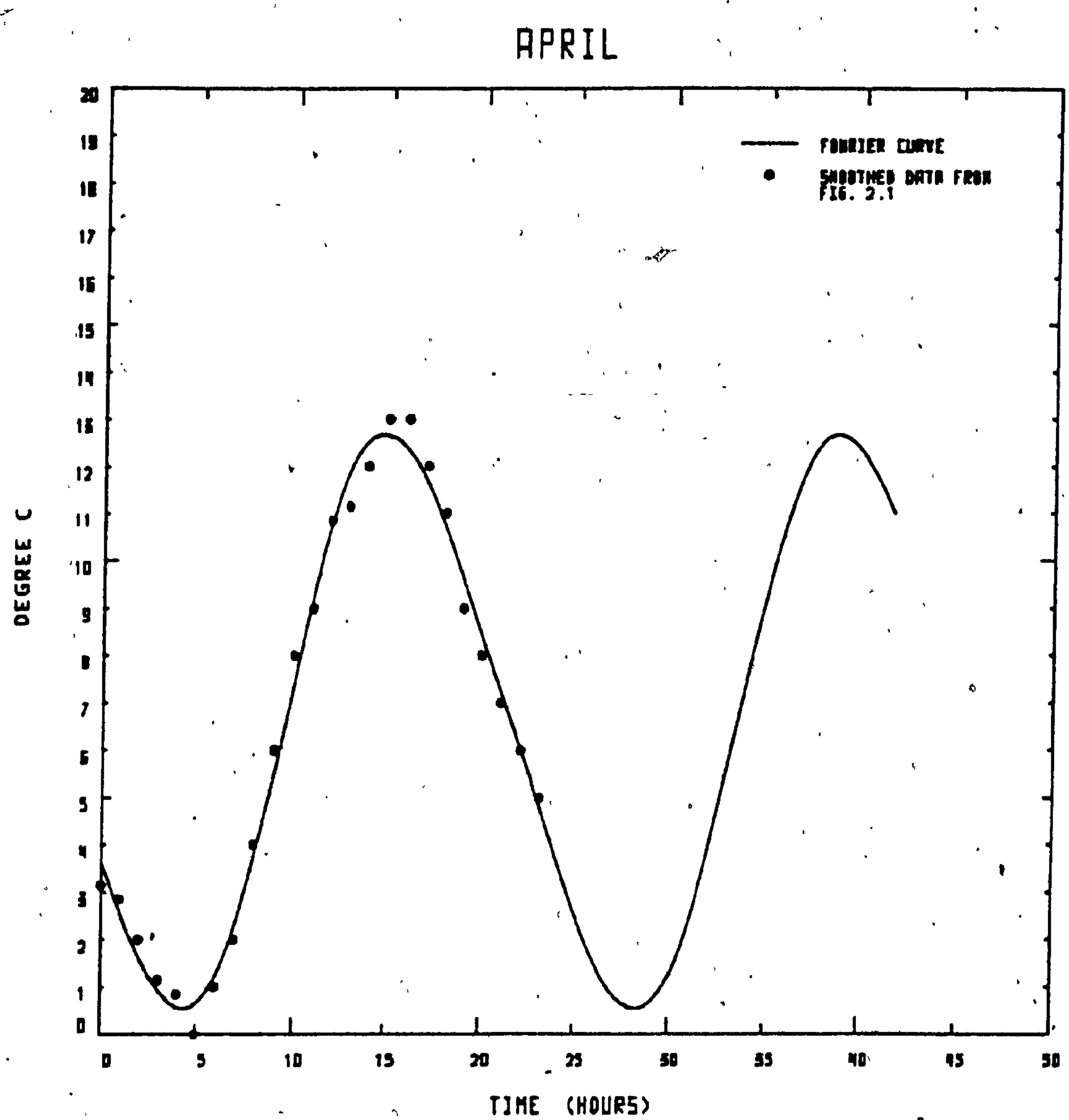


Figure 2.5. Temperature variation with weather data for April

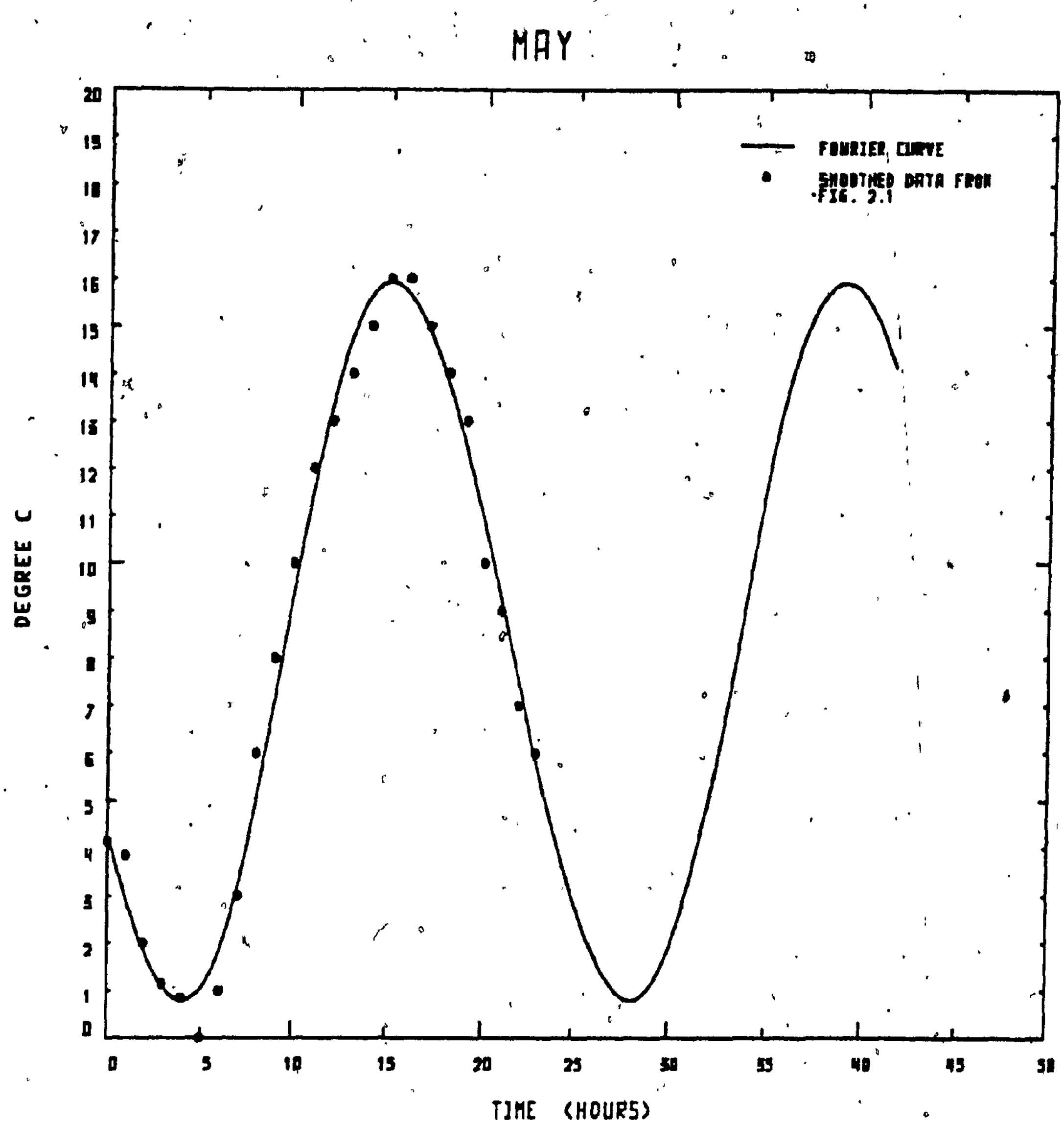


Figure 2.6 Temperature variation with weather data for May

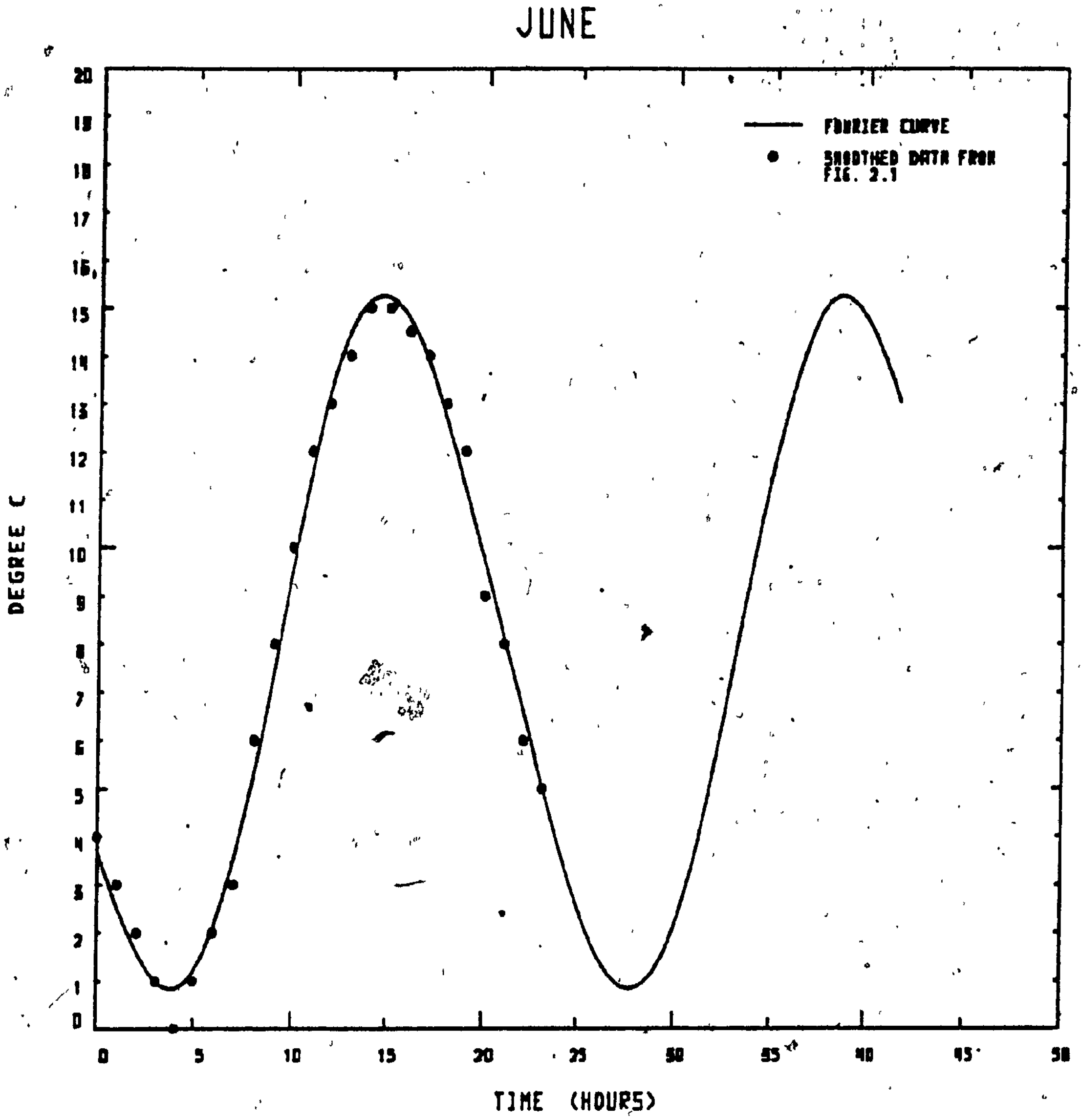


Figure 2.7 Temperature variation with weather data for June

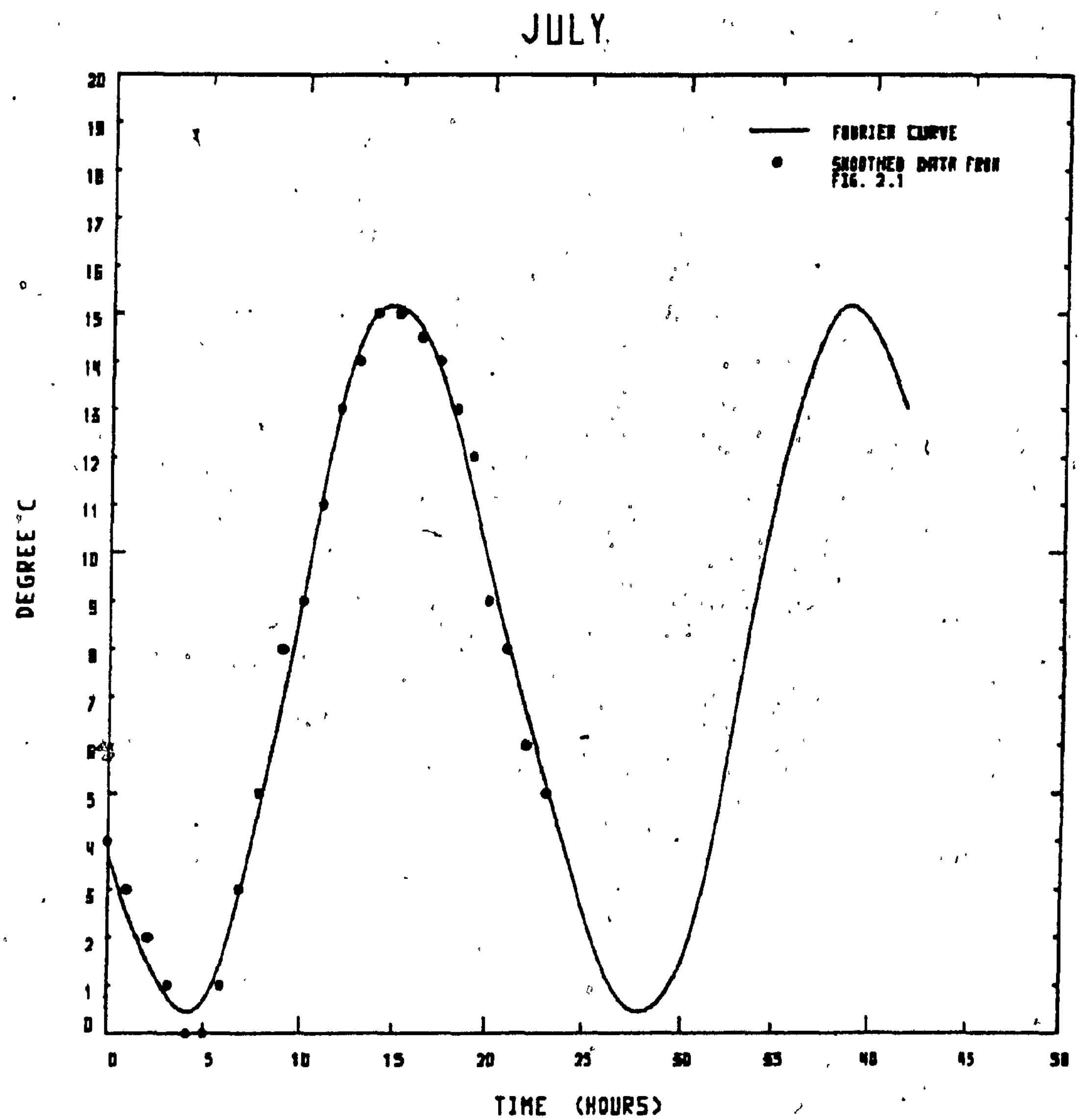


Figure 2.8 Temperature variation with weather data for July

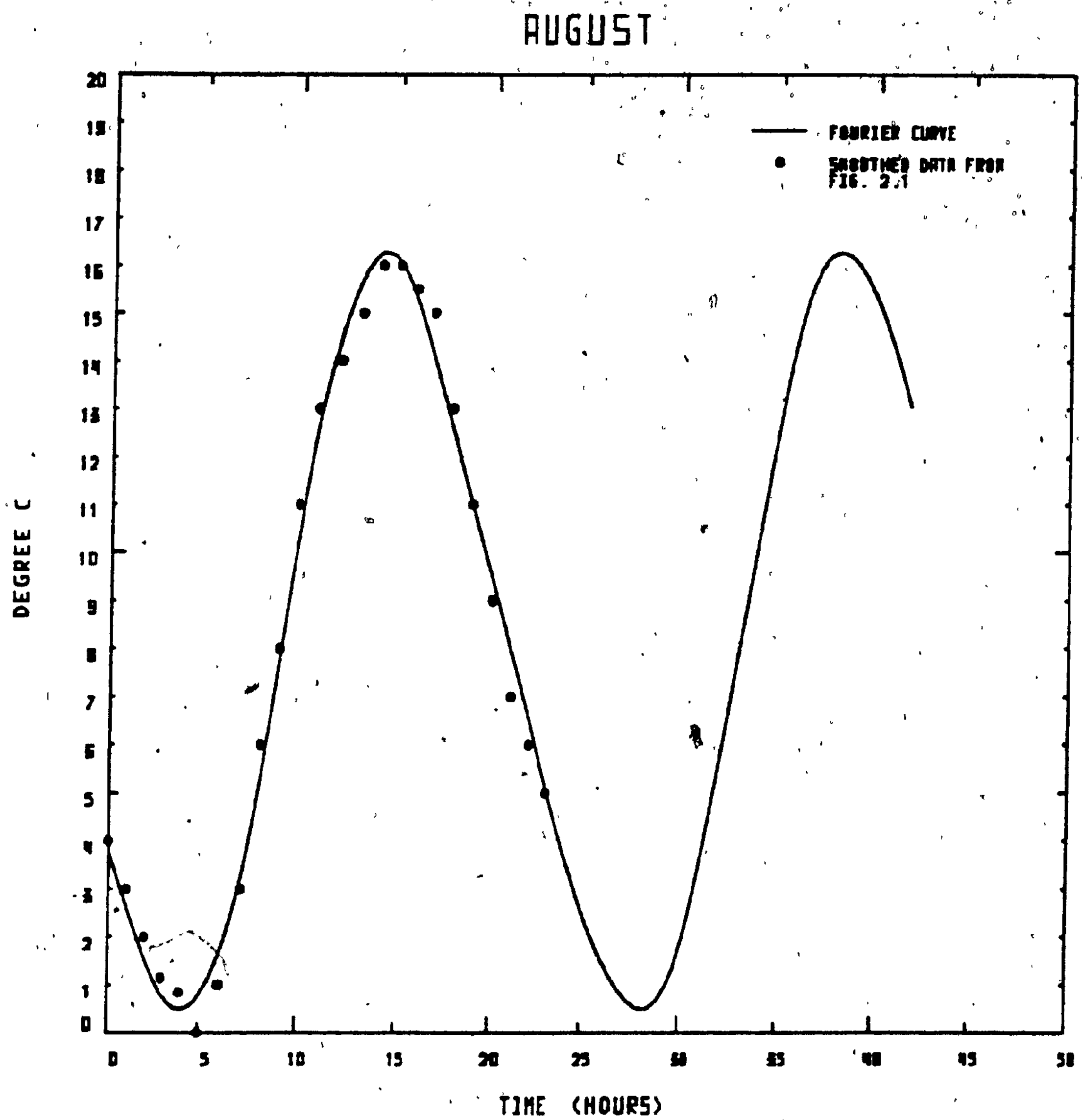


Figure 2.9 Temperature variation with weather data for August

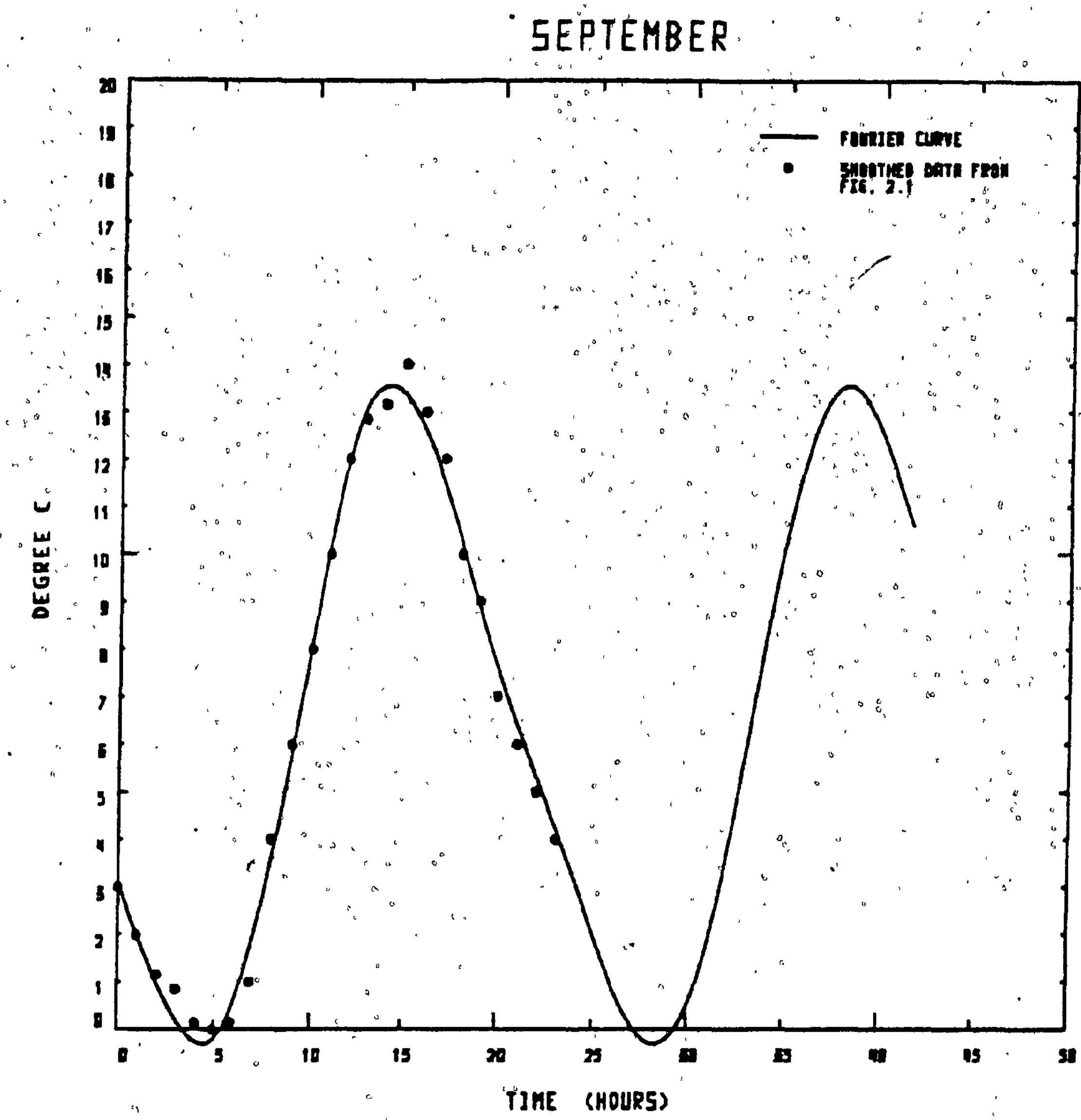


Figure 2.10 Temperature variation with weather data for September

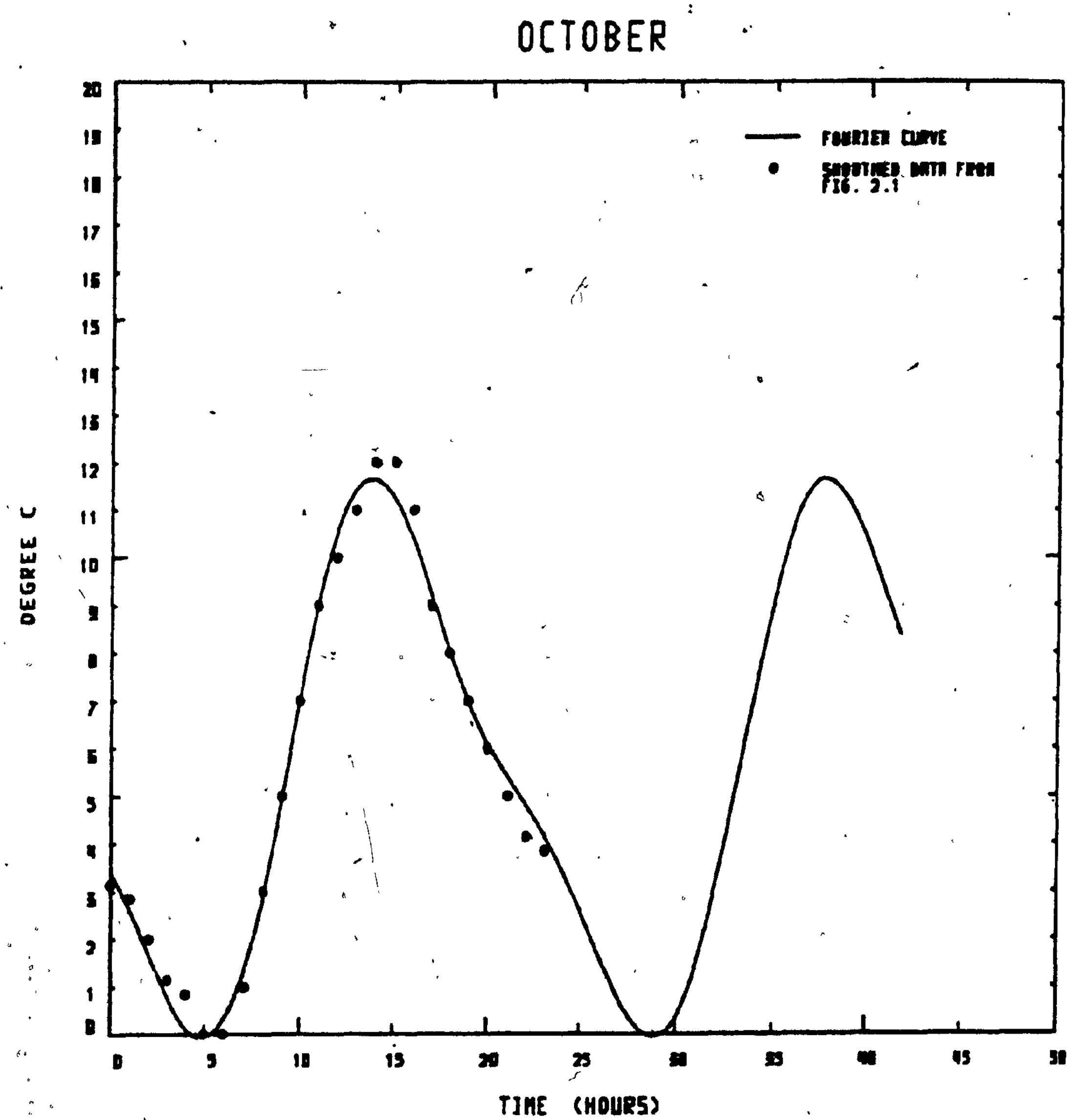


Figure 2.11 Temperature variation with weather data for October

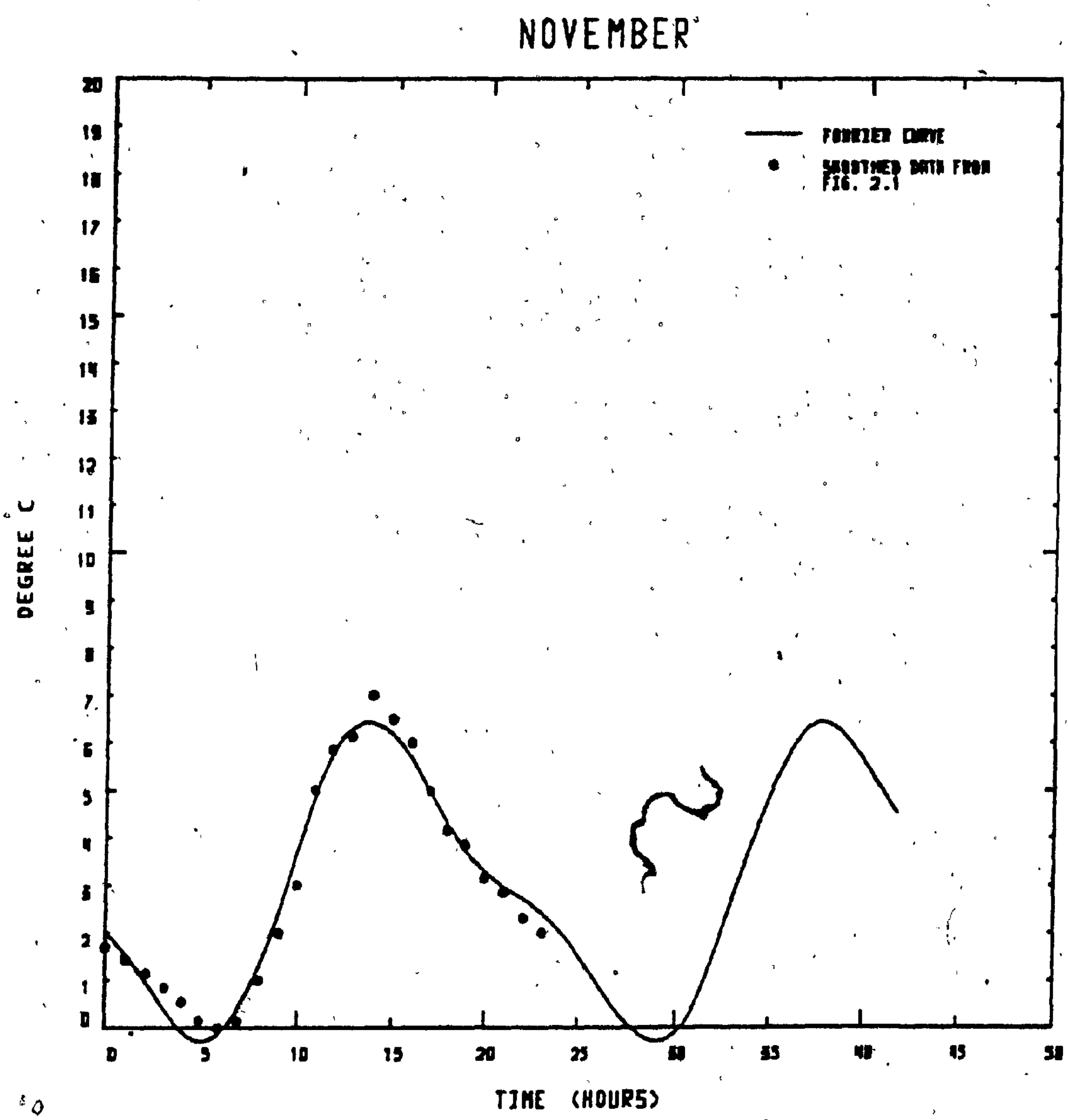


Figure 2.12 Temperature variation with weather data for November

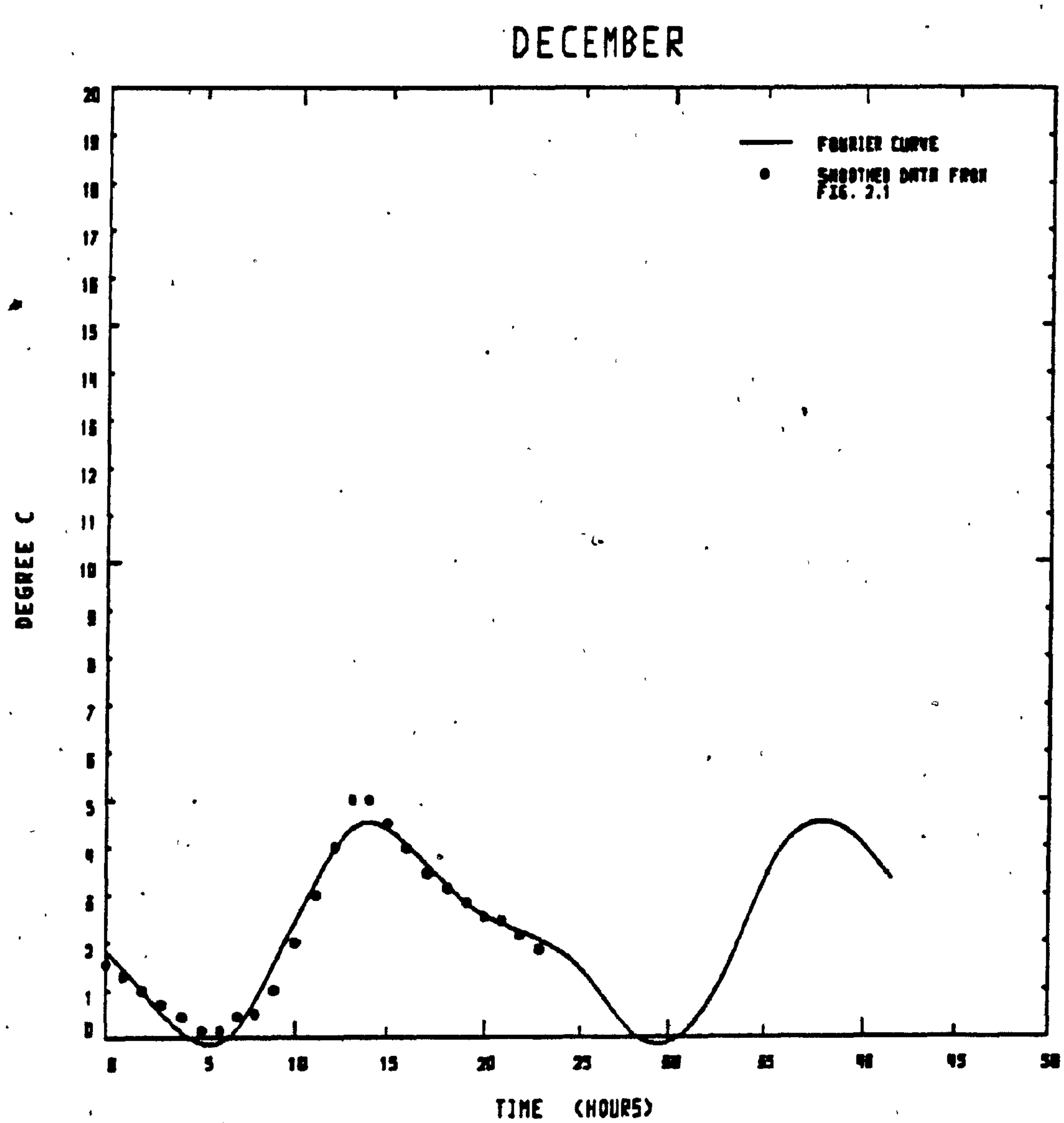


Figure 2.13 Temperature variation with weather data for December

TEMPERATURE VARIATION CURVE FITTING FOR JANUARY

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.1963$

C(1) THROUGH C(M)

C(1) = 0.3375E+01
C(2) = 0.2797E+01
C(3) = 0.8467E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	2.7	3.0	0.3
1.00	2.1	2.4	0.3
2.00	1.8	1.7	0.1
3.00	1.4	1.0	0.4
4.00	1.1	0.5	0.6
5.00	0.8	0.1	0.7
6.00	0.5	0.1	0.4
7.00	0.0	0.4	0.4
8.00	0.0	1.1	1.1
9.00	1.0	2.1	1.1
10.00	4.0	3.3	0.7
11.00	4.8	4.4	0.4
12.00	5.1	5.4	0.3
13.00	5.8	6.0	0.2
14.00	6.1	6.3	0.2
15.00	7.0	6.3	0.7
16.00	6.1	6.0	0.1
17.00	5.8	5.6	0.2
18.00	5.1	5.1	0.0
19.00	4.8	4.7	0.1
20.00	4.1	4.3	0.2
21.00	3.8	4.0	0.2
22.00	3.3	3.7	0.4
23.00	3.0	3.4	0.4

Table 2.1 Temperature variation curve fitting for January

TEMPERATURE VARIATION CURVE FITTING FOR FEBRUARY

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.1910$

C(1) THROUGH C(M)

C(1) = 0.4396E+01
C(2) = 0.3978E+01
C(3) = 0.1008E+01

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	3.1	3.7	0.6
1.00	2.8	2.9	0.1
2.00	2.0	1.9	0.1
3.00	1.3	1.0	0.3
4.00	1.0	0.3	0.7
5.00	0.7	-0.1	0.8
6.00	0.0	-0.2	0.2
7.00	0.0	0.3	0.3
8.00	1.0	1.3	0.3
9.00	2.0	2.6	0.6
10.00	4.0	4.2	0.2
11.00	5.0	5.7	0.7
12.00	7.0	7.0	0.0
13.00	8.0	7.9	0.1
14.00	9.0	8.4	0.6
15.00	9.0	8.5	0.5
16.00	8.5	8.2	0.3
17.00	8.0	7.7	0.3
18.00	7.0	7.1	0.1
19.00	6.1	6.5	0.4
20.00	5.8	5.9	0.1
21.00	5.1	5.4	0.3
22.00	4.8	4.9	0.1
23.00	4.0	4.3	0.3

Table 2.2 Temperature variation curve fitting for February

TEMPERATURE VARIATION CURVE FITTING FOR MARCH

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2429$

C(1) THROUGH C(M)

C(1) = 0.4963E+01
C(2) = 0.4462E+01
C(3) = 0.9012E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	3.1	3.3	0.2
1.00	2.8	2.5	0.3
2.00	2.0	1.6	0.4
3.00	1.0	0.9	0.1
4.00	0.3	0.3	0.0
5.00	0.0	0.1	0.1
6.00	0.3	0.4	0.1
7.00	1.0	1.1	0.1
8.00	2.0	2.3	0.3
9.00	4.0	3.8	0.2
10.00	6.0	5.4	0.6
11.00	7.0	7.0	0.0
12.00	8.0	8.3	0.3
13.00	8.8	9.2	0.4
14.00	9.1	9.6	0.5
15.00	10.0	9.6	0.4
16.00	9.5	9.2	0.3
17.00	9.0	8.6	0.4
18.00	8.0	7.8	0.2
19.00	7.0	7.0	0.0
20.00	6.0	6.3	0.3
21.00	5.1	5.6	0.5
22.00	4.8	4.9	0.1
23.00	4.0	4.1	0.1

Table 2.3 Temperature variation curve fitting for March

TEMPERATURE VARIATION CURVE FITTING FOR APRIL

POWER REGRESSION:-

Y = C(1)+C(2)*SIN(w*t+3*θ)+C(3)*SIN(2*w*t+θ)

WHERE w = 2*π/24
θ = 1.2640

C(1) THROUGH C(M)

C(1) = 0.6583E+01
C(2) = 0.5920E+01
C(3) = 0.6701E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	3.1	3.6	0.5
1.00	2.8	2.6	0.2
2.00	2.0	1.6	0.4
3.00	1.1	0.9	0.2
4.00	0.8	0.6	0.2
5.00	0.0	0.7	0.7
6.00	1.0	1.2	0.2
7.00	2.0	2.3	0.3
8.00	4.0	3.8	0.2
9.00	6.0	5.6	0.4
10.00	8.0	7.5	0.5
11.00	9.0	9.3	0.3
12.00	10.8	10.8	0.0
13.00	11.1	11.9	0.8
14.00	12.0	12.5	0.5
15.00	13.0	12.7	0.3
16.00	13.0	12.3	0.7
17.00	12.0	11.6	0.4
18.00	11.0	10.7	0.3
19.00	9.0	9.6	0.6
20.00	8.0	8.4	0.4
21.00	7.0	7.2	0.2
22.00	6.0	6.0	0.0
23.00	5.0	4.8	0.2

Table 2.4 Temperature variation curve fitting for April

TEMPERATURE VARIATION CURVE FITTING FOR MAY

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2668$

C(1) THROUGH C(M)

C(1) = 0.8333E+01
C(2) = 0.7484E+01
C(3) = 0.5584E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	4.1	4.3	0.2
1.00	3.8	2.9	0.9
2.00	2.0	1.8	0.2
3.00	1.1	1.1	0.0
4.00	0.8	0.8	0.0
5.00	0.0	1.1	1.1
6.00	1.0	1.9	0.9
7.00	3.0	3.3	0.3
8.00	6.0	5.1	0.9
9.00	8.0	7.2	0.8
10.00	10.0	9.5	0.5
11.00	12.0	11.6	0.4
12.00	13.0	13.4	0.4
13.00	14.0	14.8	0.8
14.00	15.0	15.7	0.7
15.00	16.0	15.9	0.1
16.00	16.0	15.6	0.4
17.00	15.0	14.9	0.1
18.00	14.0	13.7	0.3
19.00	13.0	12.3	0.7
20.00	10.0	10.8	0.8
21.00	9.0	9.1	0.1
22.00	7.0	7.4	0.4
23.00	6.0	5.8	0.2

Table 2.5 Temperature variation curve fitting for May

TEMPERATURE VARIATION CURVE FITTING FOR JUNE

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2951$

C(1) THROUGH C(M)

C(1) = 0.7938E+01
C(2) = 0.7115E+01
C(3) = 0.5883E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	4.0	3.7	0.3
1.00	3.0	2.5	0.5
2.00	2.0	1.6	0.4
3.00	1.0	1.0	0.0
4.00	0.0	0.8	0.8
5.00	1.0	1.2	0.2
6.00	2.0	2.1	0.1
7.00	3.0	3.6	0.6
8.00	6.0	5.4	0.6
9.00	8.0	7.5	0.5
10.00	10.0	9.6	0.4
11.00	12.0	11.6	0.4
12.00	13.0	13.3	0.3
13.00	14.0	14.5	0.5
14.00	15.0	15.1	0.1
15.00	15.0	15.2	0.2
16.00	14.5	14.7	0.2
17.00	14.0	13.8	0.2
18.00	13.0	12.6	0.4
19.00	12.0	11.2	0.8
20.00	9.0	9.6	0.6
21.00	8.0	8.1	0.1
22.00	6.0	6.5	0.5
23.00	5.0	5.1	0.1

Table 2.6 Temperature variation curve fitting for June

TEMPERATURE VARIATION CURVE FITTING FOR JULY

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2798$

C(1) THROUGH C(M)

C(1) = 0.7729E+01
C(2) = 0.7225E+01
C(3) = 0.7075E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	4.0	3.8	0.2
1.00	3.0	2.5	0.5
2.00	2.0	1.5	0.5
3.00	1.0	0.7	0.3
4.00	0.0	0.5	0.5
5.00	0.0	0.7	0.7
6.00	1.0	1.5	0.5
7.00	3.0	2.9	0.1
8.00	5.0	4.7	0.3
9.00	8.0	6.9	1.1
10.00	9.0	9.1	0.1
11.00	11.0	11.3	0.3
12.00	13.0	13.1	0.1
13.00	14.0	14.3	0.3
14.00	15.0	15.0	0.0
15.00	15.0	15.1	0.1
16.00	14.5	14.7	0.2
17.00	14.0	13.8	0.2
18.00	13.0	12.6	0.4
19.00	12.0	11.2	0.8
20.00	9.0	9.7	0.7
21.00	8.0	8.2	0.2
22.00	6.0	6.6	0.6
23.00	5.0	5.2	0.2

Table 2.7 Temperature variation curve fitting for July

TEMPERATURE VARIATION CURVE FITTING FOR AUGUST

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.3084$

C(1) THROUGH C(M)

C(1) = 0.8146E+01
C(2) = 0.7628E+01
C(3) = 0.1058E+01

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	4.0	3.8	0.2
1.00	3.0	2.6	0.4
2.00	2.0	1.5	0.5
3.00	1.1	0.8	0.3
4.00	0.8	0.5	0.3
5.00	0.0	0.8	0.8
6.00	1.0	1.7	0.7
7.00	3.0	3.3	0.3
8.00	6.0	5.4	0.6
9.00	8.0	7.9	0.1
10.00	11.0	10.4	0.6
11.00	13.0	12.7	0.3
12.00	14.0	14.6	0.6
13.00	15.0	15.8	0.8
14.00	16.0	16.3	0.3
15.00	16.0	16.0	0.0
16.00	15.5	15.2	0.3
17.00	15.0	14.0	1.0
18.00	13.0	12.5	0.5
19.00	11.0	10.9	0.1
20.00	9.0	9.4	0.4
21.00	7.0	7.9	0.9
22.00	6.0	6.5	0.5
23.00	5.0	5.1	0.1

Table 2.8 Temperature variation curve fitting for August

TEMPERATURE VARIATION CURVE FITTING FOR SEPTEMBER

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2958$

C(1) THROUGH C(M)

C(1) = 0.6429E+01
C(2) = 0.6574E+01
C(3) = 0.1155E+01

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	3.0	3.1	0.1
1.00	2.0	2.0	0.0
2.00	1.1	1.0	0.1
3.00	0.8	0.2	0.6
4.00	0.1	-0.3	0.4
5.00	0.0	-0.2	0.2
6.00	0.1	0.5	0.4
7.00	1.0	1.8	0.8
8.00	4.0	3.6	0.4
9.00	6.0	5.9	0.1
10.00	8.0	8.2	0.2
11.00	10.0	10.3	0.3
12.00	12.0	12.0	0.0
13.00	12.8	13.1	0.3
14.00	13.1	13.5	0.4
15.00	14.0	13.3	0.7
16.00	13.0	12.6	0.4
17.00	12.0	11.4	0.6
18.00	10.0	10.1	0.1
19.00	9.0	8.8	0.2
20.00	7.0	7.6	0.6
21.00	6.0	6.4	0.4
22.00	5.0	5.3	0.3
23.00	4.0	4.2	0.2

Table 2.9 Temperature variation curve fitting for September

TEMPERATURE VARIATION CURVE FITTING FOR OCTOBER

POWER REGRESSION:-

Y = C(1)+C(2)*SIN(w*t+3*θ)+C(3)*SIN(2*w*t+θ)

WHERE w = 2*π/24
θ = 1.2975

C(1) THROUGH C(M)

C(1) = 0.5583E+01
C(2) = 0.5233E+01
C(3) = 0.1464E+01

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	3.1	3.4	0.3
1.00	2.8	2.6	0.2
2.00	2.0	1.6	0.4
3.00	1.1	0.7	0.4
4.00	0.8	0.1	0.7
5.00	0.0	-0.1	0.1
6.00	0.0	0.3	0.3
7.00	1.0	1.4	0.4
8.00	3.0	3.0	0.0
9.00	5.0	5.0	0.0
10.00	7.0	7.1	0.1
11.00	9.0	9.1	0.1
12.00	10.0	10.6	0.6
13.00	11.0	11.4	0.4
14.00	12.0	11.6	0.4
15.00	12.0	11.2	0.8
16.00	11.0	10.3	0.7
17.00	9.0	9.2	0.2
18.00	8.0	8.0	0.0
19.00	7.0	6.9	0.1
20.00	6.0	6.1	0.1
21.00	5.0	5.4	0.4
22.00	4.1	4.8	0.7
23.00	3.8	4.1	0.3

Table 2.10 Temperature variation curve fitting for October

TEMPERATURE VARIATION CURVE FITTING FOR NOVEMBER

POWER REGRESSION:-

Y = C(1)+C(2)*SIN(w*t+3* θ)+C(3)*SIN(2*w*t+ θ)

WHERE w = 2* π/24
θ = 1.2820

C(1) THROUGH C(M)

C(1) = 0.2992E+01
C(2) = 0.2909E+01
C(3) = 0.9465E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	1.7	2.0	0.3
1.00	1.4	1.5	0.1
2.00	1.1	0.9	0.2
3.00	0.8	0.4	0.4
4.00	0.5	-0.1	0.6
5.00	0.1	-0.3	0.4
6.00	0.0	-0.1	0.1
7.00	0.1	0.4	0.3
8.00	1.0	1.3	0.3
9.00	2.0	2.5	0.5
10.00	3.0	3.7	0.7
11.00	5.0	4.9	0.1
12.00	5.8	5.8	0.0
13.00	6.1	6.3	0.2
14.00	7.0	6.4	0.6
15.00	6.5	6.2	0.3
16.00	6.0	5.6	0.4
17.00	5.0	5.0	0.0
18.00	4.1	4.3	0.2
19.00	3.8	3.7	0.1
20.00	3.1	3.3	0.2
21.00	2.8	3.0	0.2
22.00	2.3	2.7	0.4
23.00	2.0	2.4	0.4

Table 2.11 Temperature variation curve fitting for November

TEMPERATURE VARIATION CURVE FITTING FOR DECEMBER

POWER REGRESSION:-

$$Y = C(1)+C(2)*SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2422$

C(1) THROUGH C(M)

C(1) = 0.2217E+01
C(2) = 0.1979E+01
C(3) = 0.7186E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
0.00	1.5	1.8	0.3
1.00	1.3	1.4	0.1
2.00	1.0	1.0	0.0
3.00	0.7	0.5	0.2
4.00	0.4	0.1	0.3
5.00	0.1	-0.1	0.2
6.00	0.1	-0.1	0.2
7.00	0.4	0.2	0.2
8.00	0.5	0.8	0.3
9.00	1.0	1.6	0.6
10.00	2.0	2.5	0.5
11.00	3.0	3.3	0.3
12.00	4.0	4.0	0.0
13.00	5.0	4.4	0.6
14.00	5.0	4.5	0.5
15.00	4.5	4.4	0.1
16.00	4.0	4.1	0.1
17.00	3.4	3.6	0.2
18.00	3.1	3.2	0.1
19.00	2.8	2.8	0.0
20.00	2.5	2.6	0.1
21.00	2.4	2.4	0.0
22.00	2.1	2.2	0.1
23.00	1.8	2.1	0.3

Table 2.12 Temperature variation curve fitting for December

with an Analogue/Digital converter card and a battery operated clock. Suitable filters to prevent signals induced by elevator switch sparks or T.V. stations from changing the switch channel were installed. The data collection is controlled through a program which will be discussed later.

Wires are used to connect the joystick socket (Fig. 2.14, Table 2.13) [5] of the computer to the switch control. Within the joystick socket, there are 4 annunciators, AN0, AN1, AN2 and AN3. When AN2 is triggered, the switch scanner is reset to the first sensor connection. The scanner is switched to the next sensor each time AN0 is triggered, to read the desired measurement.

The A/D converter [6] transforms the electric voltage received through the amplifier into Binary Coded Decimal numbers for storage by the Apple II+ computer.

The data acquisition program as well as the program to retrieve data are listed in Appendix B. The time interval between each reading is user selectable. The B.C.D. data is translated into simple binary code and sorted into separate files, periodically stored on disk. The retrieve data program is used to transfer data from disk for calculation or display.

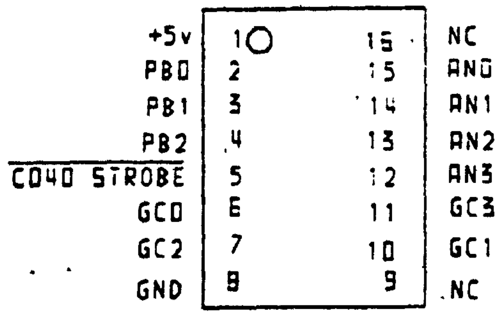


Figure 2.14 Game Input/Output connector pinout

Table 2.13 Game I/O connector signal Descriptions

Pin	Name	Description
1	+5 v	+5 volt power supply. Total current drain on this pin must be less than 100mA
2-4	PB0-PB2	Single-bit (Pushbutton) inputs. These are standard 74LS series TTL inputs
5	C040 STROBE	A general-purpose s*robe This line, usually high, goes lou during ½C of a read or write cycle to any address from $C040 through $C04F. This is a standard 74LS TTL output
6,7,10,11	GC0-GC3	Game controller inputs. These should each be connected through a 150K Ohm variable resistor to +5v
8	GND	System electrical ground
12-15	AN0-AN3	Annunciator outputs. These are standard 74LS series TTL outputs and must be buffered if used to drive other than TTL inputs
9,16	NC	No internal connection

2.3 Comparison Between the Theoretical and Experimental Curves

Using monitored temperatures for 24 hours, an experimental curve was generated with the curve-fit program by a least squares fit to equation (2.3) when the parameters C(2), C(3) and θ were varied systematically. This was compared to the monthly average Historic curve, placed to have the same 24 hour average temperature, C(1) as the experimental curve. The experimental temperatures, curves and absolute differences are shown in Fig. 2.15 - Fig. 2.20 and Table 2.14 - Table 2.19. Two observations drawn from these graphs are:

1. The curves are very simillar for normal weather conditions, and are inconsistent when weather fronts (Fig. 2.18) pass through.
2. Larger differences between the two curves are observed mainly at the beginning of the month. (e.g. Fig. 2.17).

It seems that a month is too long a period for calculating the constants in equation (2.3). Therefore the constants used were changed twice a month. On the last seven or eight days of each month, and the first eight days of the next month, the averages of the 2 sets of monthly constants determined above were used. The better fits obtained in this way for Nov. 7 and Nov. 29 are shown in Fig. 2.21 and Fig. 2.22.

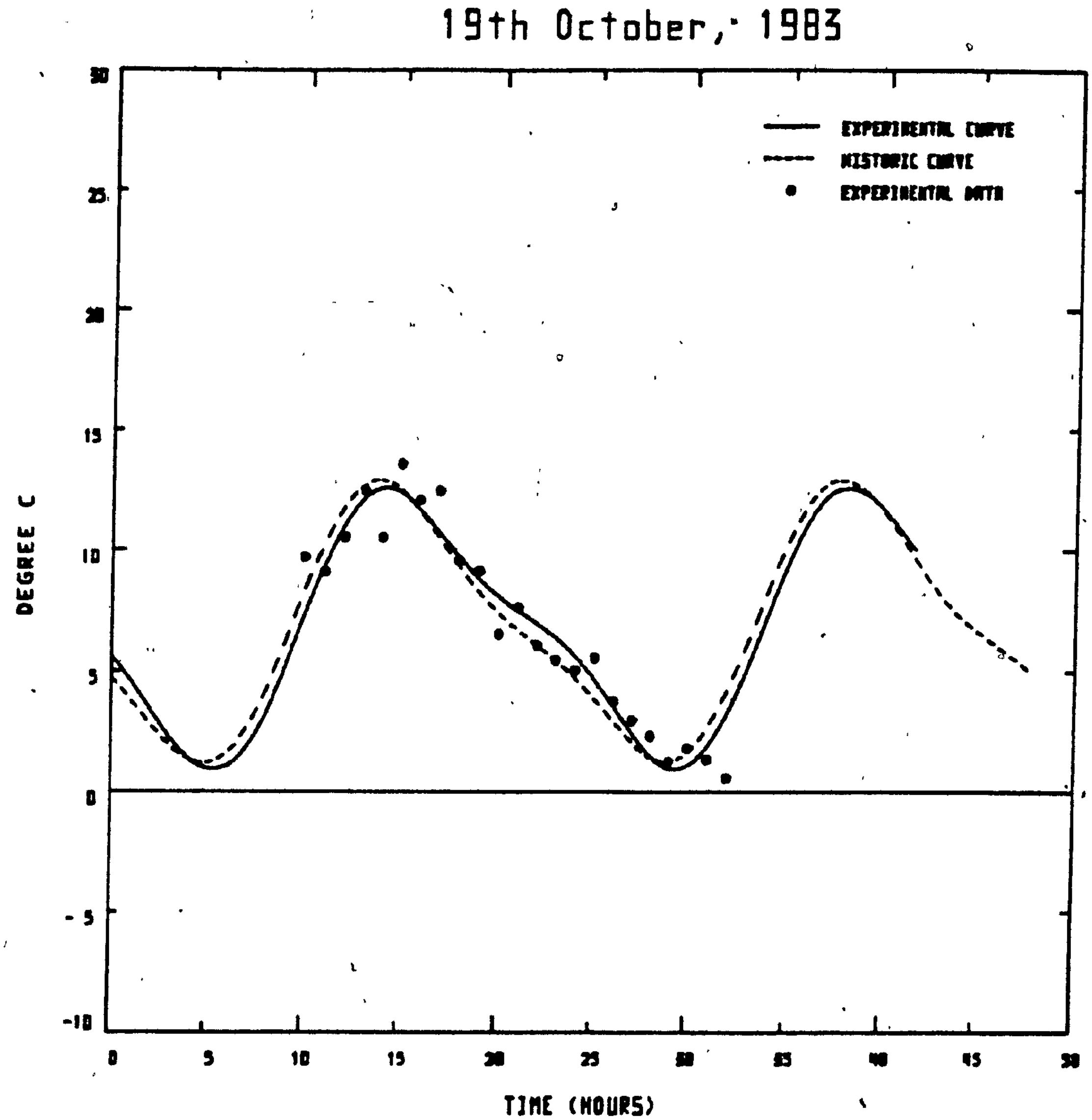


Figure 2.15 Comparison of historic curve and experimental weather data for 19th October, 1983.

TEMPERATURE VARIATION CURVE FITTING FOR 19th October, 1983

POWER REGRESSION:-

$$Y = C(1)+C(2)SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2360$

C(1) THROUGH C(M)

C(1) = 0.6878E+01
C(2) = 0.5111E+01
C(3) = 0.1573E+01

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
10.00	9.7	7.4	2.3
11.00	9.1	9.4	0.3
12.00	10.6	11.1	0.5
13.00	12.5	12.2	0.3
14.00	10.6	12.6	2.0
15.00	13.6	12.4	1.2
16.00	12.1	11.7	0.4
17.00	12.5	10.7	1.8
18.00	9.6	9.7	0.1
19.00	9.2	8.8	0.4
20.00	6.5	8.1	1.5
21.00	7.6	7.5	0.2
22.00	6.1	7.0	0.9
23.00	5.5	6.4	0.9
24.00	5.0	5.6	0.6
25.00	5.6	4.7	0.9
26.00	3.8	3.5	0.2
27.00	3.0	2.4	0.6
28.00	2.3	1.5	0.9
29.00	1.2	1.0	0.3
30.00	1.8	1.1	0.7
31.00	1.3	1.9	0.5
32.00	0.6	3.3	2.7

Table 2.14 Temperature variation curve fitting for 19th October, 1983

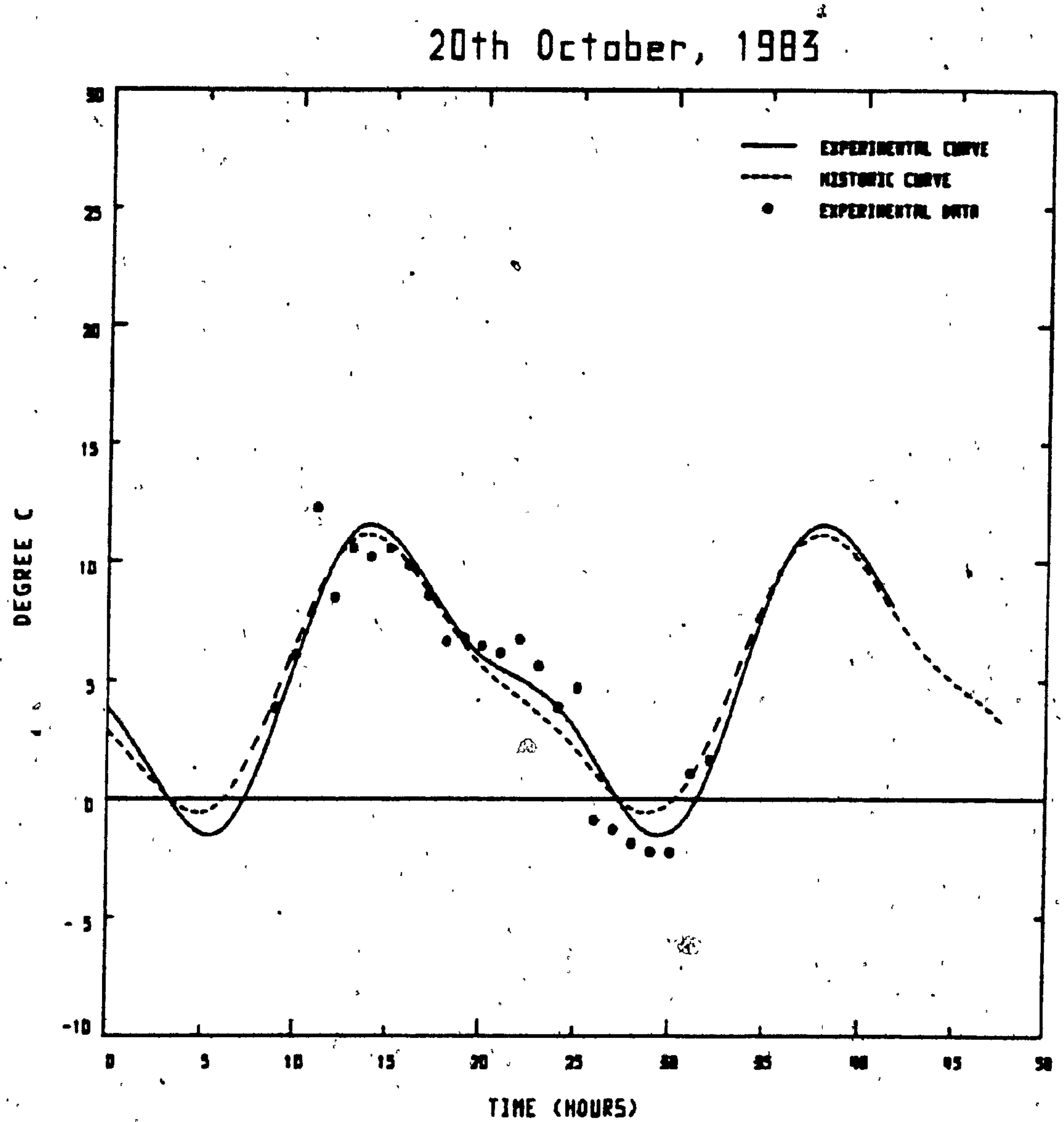


Figure 2.16 Comparison of historic curve and experimental weather data for 20th October, 1983.

TEMPERATURE VARIATION CURVE FITTING FOR 20th October, 1983

POWER REGRESSION:-

Y = C(1)+C(2)SIN(w*t+3*θ)+C(3)*SIN(2*w*t+θ)

WHERE w = 2*π/24
θ = 1.2462

C(1) THROUGH C(M)

C(1) = 0.5073E+01
C(2) = 0.5528E+01
C(3) = 0.2003E+01

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
9.00	3.8	3.4	0.5
10.00	6.1	5.9	0.2
11.00	12.3	8.2	4.1
12.00	8.5	10.1	1.6
13.00	10.6	11.2	0.7
14.00	10.2	11.6	1.3
15.00	10.6	11.1	0.6
16.00	9.8	10.2	0.3
17.00	8.6	9.0	0.4
18.00	6.6	7.7	1.1
19.00	6.8	6.7	0.1
20.00	6.5	6.0	0.5
21.00	6.2	5.5	0.7
22.00	6.7	5.1	1.7
23.00	5.6	4.6	1.0
24.00	3.9	3.9	0.0
25.00	4.7	2.9	1.8
26.00	-0.9	1.6	2.5
27.00	-1.3	0.3	1.5
28.00	-1.9	-0.8	1.0
29.00	-2.2	-1.5	0.8
30.00	-2.3	-1.4	0.9
31.00	1.1	-0.5	1.6
32.00	1.6	1.2	0.5

Table 2.15 Temperature variation curve fitting for 20th October, 1983

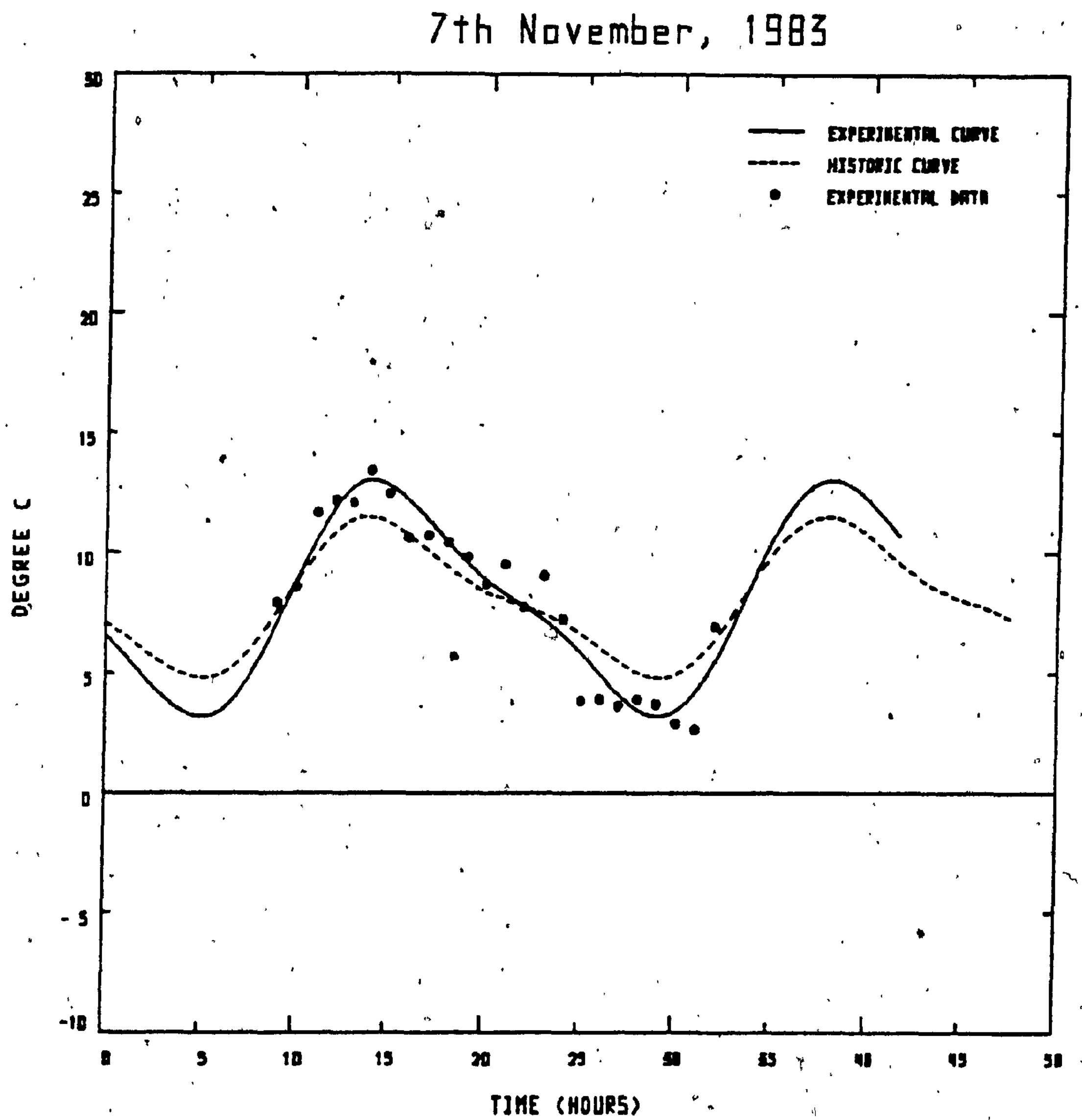


Figure 2.17 Comparison of historic curve and experimental weather data for 7th November, 1983.

TEMPERATURE VARIATION CURVE FITTING FOR 7th November, 1983

POWER REGRESSION:-

$$Y = C(1)+C(2)SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2651$

C(1) THROUGH C(M)

C(1) = 0.8077E+01
C(2) = 0.4391E+01
C(3) = 0.1224E+01

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
9.00	7.9	7.1	0.8
10.00	8.6	8.9	0.3
11.00	11.7	10.6	1.1
12.00	12.2	11.9	0.3
13.00	12.1	12.8	0.7
14.00	13.4	13.0	0.4
15.00	12.5	12.8	0.3
16.00	10.6	12.2	1.5
17.00	10.7	11.3	0.6
18.00	10.4	10.4	0.0
19.00	9.8	9.6	0.3
20.00	8.7	8.9	0.1
21.00	9.5	8.3	1.3
22.00	7.8	7.8	0.0
23.00	9.1	7.2	1.8
24.00	7.2	6.6	0.7
25.00	3.8	5.8	2.0
26.00	3.9	4.9	1.0
27.00	3.6	4.1	0.5
28.00	3.9	3.5	0.4
29.00	3.7	3.2	0.5
30.00	2.9	3.4	0.5
31.00	2.6	4.2	1.6
32.00	6.9	5.5	1.4

Table 2.16 Temperature variation curve fitting for 7th November, 1983

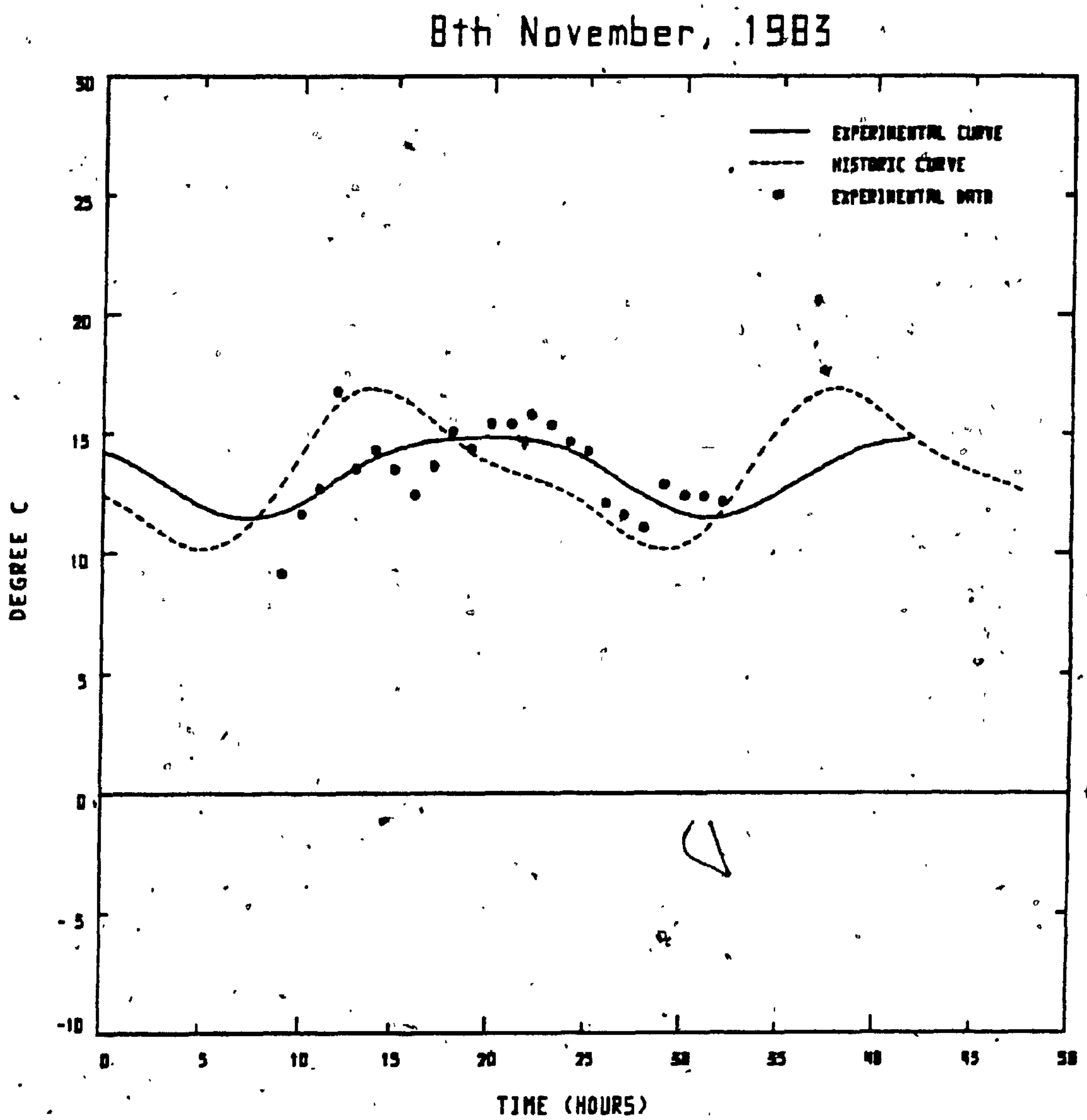


Figure 2.18 Comparison of historic curve and experimental weather data for 8th November, 1983.

TEMPERATURE VARIATION CURVE FITTING FOR 8th November, 1983

POWER REGRESSION:-

$$Y = C(1)+C(2)SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$

$\theta = 0.9261$

C(1) THROUGH C(M)

C(1) = 0.1345E+02
C(2) = 0.1685E+01
C(3) = 0.2946E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
9.00	9.2	11.7	2.6
10.00	11.6	12.1	0.5
11.00	12.7	12.6	0.1
12.00	16.8	13.1	3.7
13.00	13.5	13.6	0.1
14.00	14.3	14.0	0.4
15.00	13.5	14.3	0.8
16.00	12.5	14.5	2.1
17.00	13.6	14.7	1.0
18.00	15.1	14.8	0.3
19.00	14.4	14.8	0.4
20.00	15.4	14.8	0.6
21.00	15.4	14.8	0.6
22.00	15.8	14.7	1.1
23.00	15.4	14.5	0.8
24.00	14.6	14.3	0.4
25.00	14.3	13.9	0.4
26.00	12.1	13.4	1.3
27.00	11.6	12.9	1.3
28.00	11.1	12.4	1.3
29.00	12.9	12.0	0.9
30.00	12.4	11.6	0.8
31.00	12.4	11.5	0.9
32.00	12.1	11.5	0.6

Table 2.17 Temperature variation curve fitting for 8th November, 1983

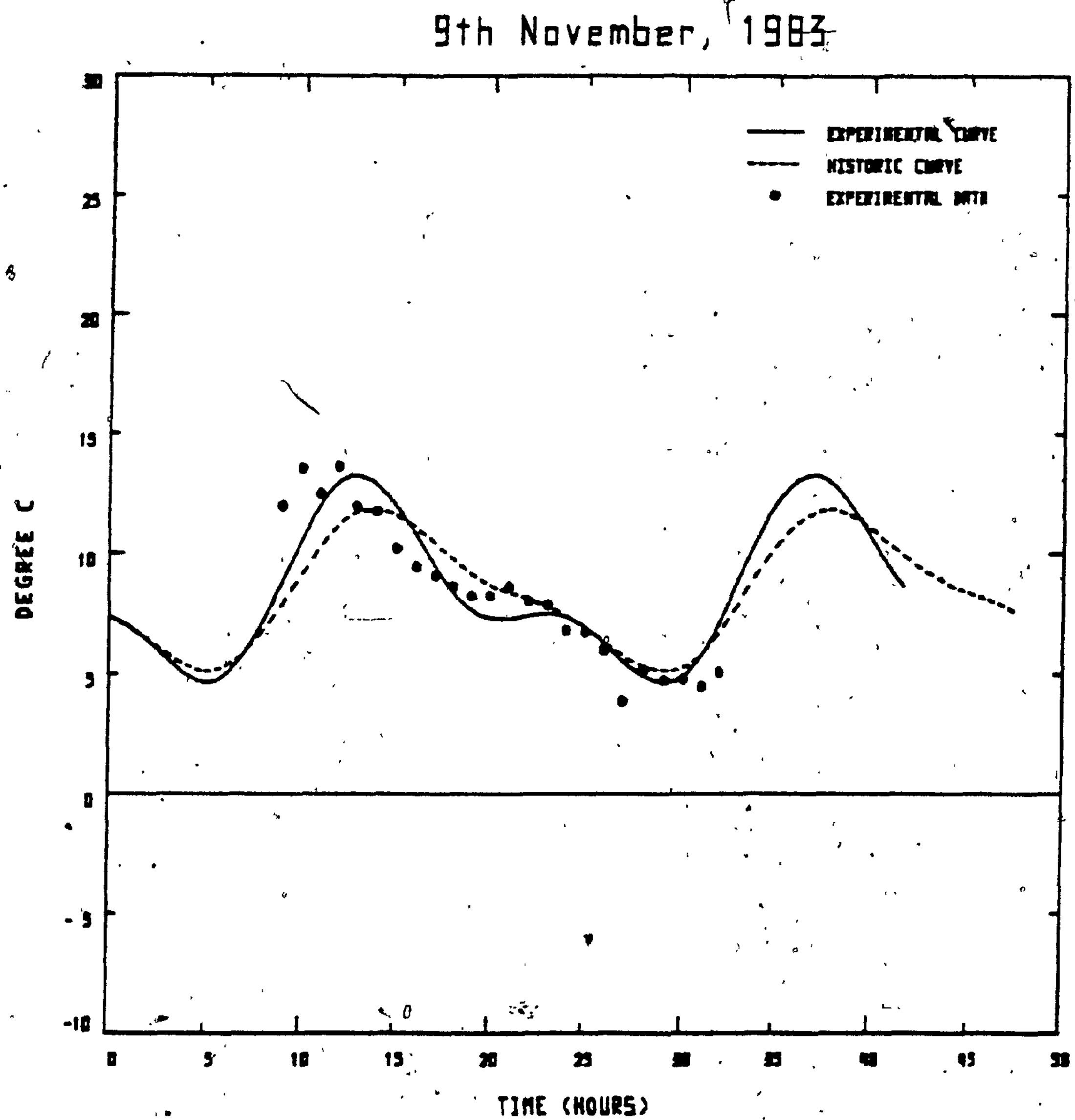


Figure 2.19 Comparison of historic curve and experimental weather data for 9th November, 1983.

TEMPERATURE VARIATION CURVE FITTING FOR 9th November, 1983

POWER REGRESSION:-

$$Y = C(1)+C(2)SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.3884$

C(1) THROUGH C(M)

C(1) = 0.8408E+01
C(2) = 0.3287E+01
C(3) = 0.1808E+01

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
9.00	12.0	8.9	3.1
10.00	13.6	10.6	3.0
11.00	12.5	12.1	0.5
12.00	13.6	13.0	0.7
13.00	12.0	13.3	1.3
14.00	11.8	12.9	1.1
15.00	10.2	11.9	1.7
16.00	9.5	10.7	1.2
17.00	9.1	9.4	0.3
18.00	8.6	8.3	0.3
19.00	8.3	7.6	0.6
20.00	8.2	7.3	0.9
21.00	8.6	7.3	1.3
22.00	8.1	7.4	0.6
23.00	7.9	7.5	0.4
24.00	6.8	7.4	0.5
25.00	6.8	7.0	0.2
26.00	6.0	6.3	0.3
27.00	3.9	5.5	1.7
28.00	5.2	4.9	0.3
29.00	4.7	4.7	0.1
30.00	4.8	4.9	0.1
31.00	4.5	5.8	1.3
32.00	5.1	7.2	2.1

Table 2.18 Temperature variation curve fitting for 9th November, 1983

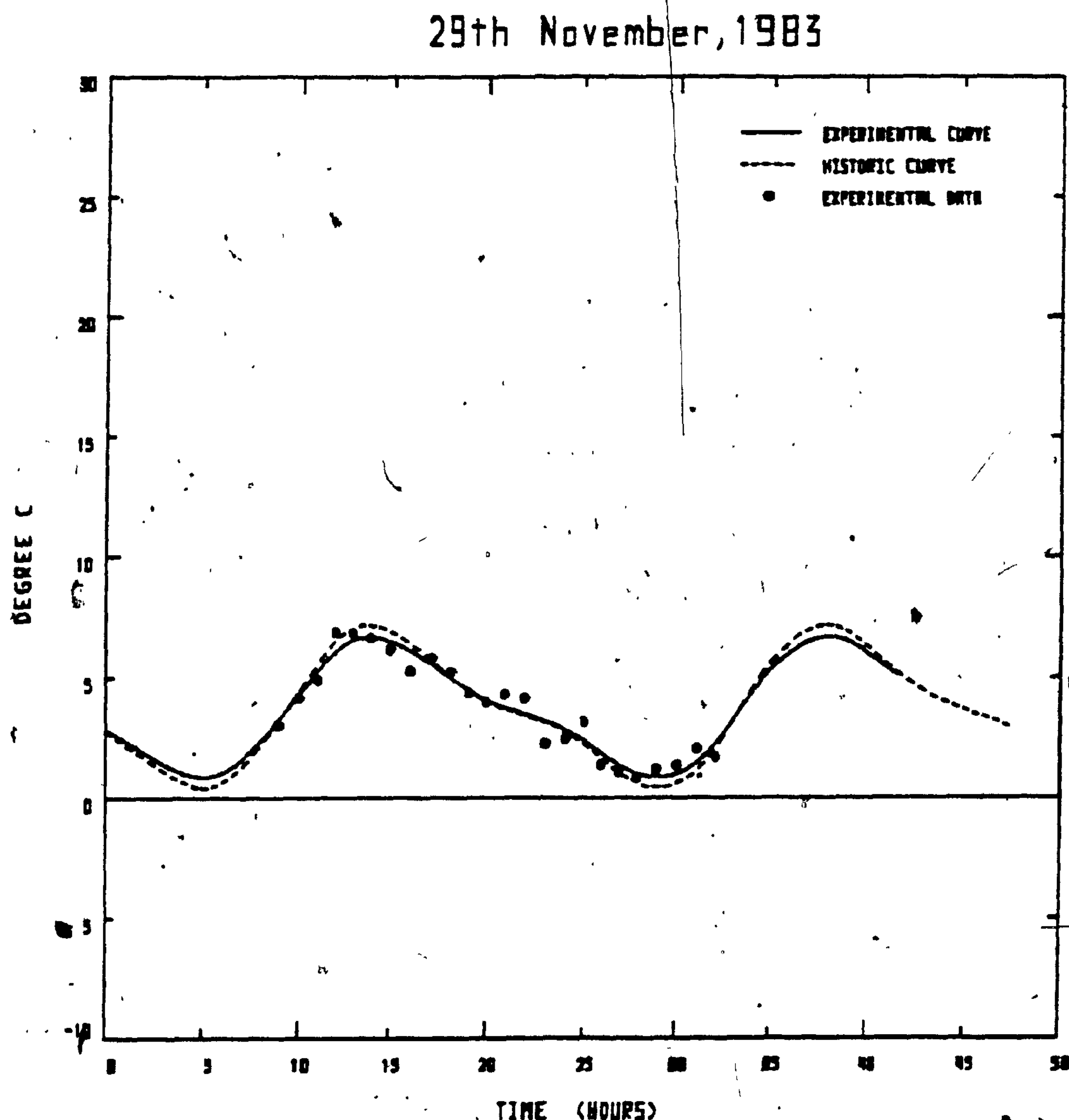


Figure 2.20 Comparison of historic curve and experimental weather data for 29th November, 1983.

TEMPERATURE VARIATION CURVE FITTING FOR 29th November,1983

POWER REGRESSION:-

$$Y = C(1)+C(2)SIN(w*t+3*\theta)+C(3)*SIN(2*w*t+\theta)$$

WHERE $w = 2*\pi/24$
$\theta = 1.2760$

C(1) THROUGH C(M)

C(1) = 0.3718E+01
C(2) = 0.2558E+01
C(3) = 0.7006E+00

ACTUAL t	ACTUAL Y	CALCULATED Y	ABSOLUTE DIFFERENCE
9.00	3.0	3.3	0.2
10.00	4.2	4.3	0.1
11.00	4.9	5.3	0.4
12.00	6.9	6.0	0.9
13.00	6.8	6.5	0.4
14.00	6.6	6.6	0.0
15.00	6.2	6.5	0.3
16.00	5.3	6.1	0.8
17.00	5.8	5.6	0.2
18.00	5.2	5.0	0.2
19.00	4.4	4.5	0.2
20.00	4.0	4.1	0.1
21.00	4.3	3.8	0.5
22.00	4.1	3.5	0.7
23.00	2.3	3.1	0.9
24.00	2.4	2.8	0.3
25.00	3.2	2.3	0.8
26.00	1.4	1.8	0.5
27.00	1.1	1.4	0.3
28.00	0.8	1.0	0.2
29.00	1.2	0.9	0.3
30.00	1.4	1.1	0.3
31.00	2.0	1.5	0.5
32.00	1.7	2.3	0.6

Table 2.19 Temperature variation curve fitting for 29th November, 1983

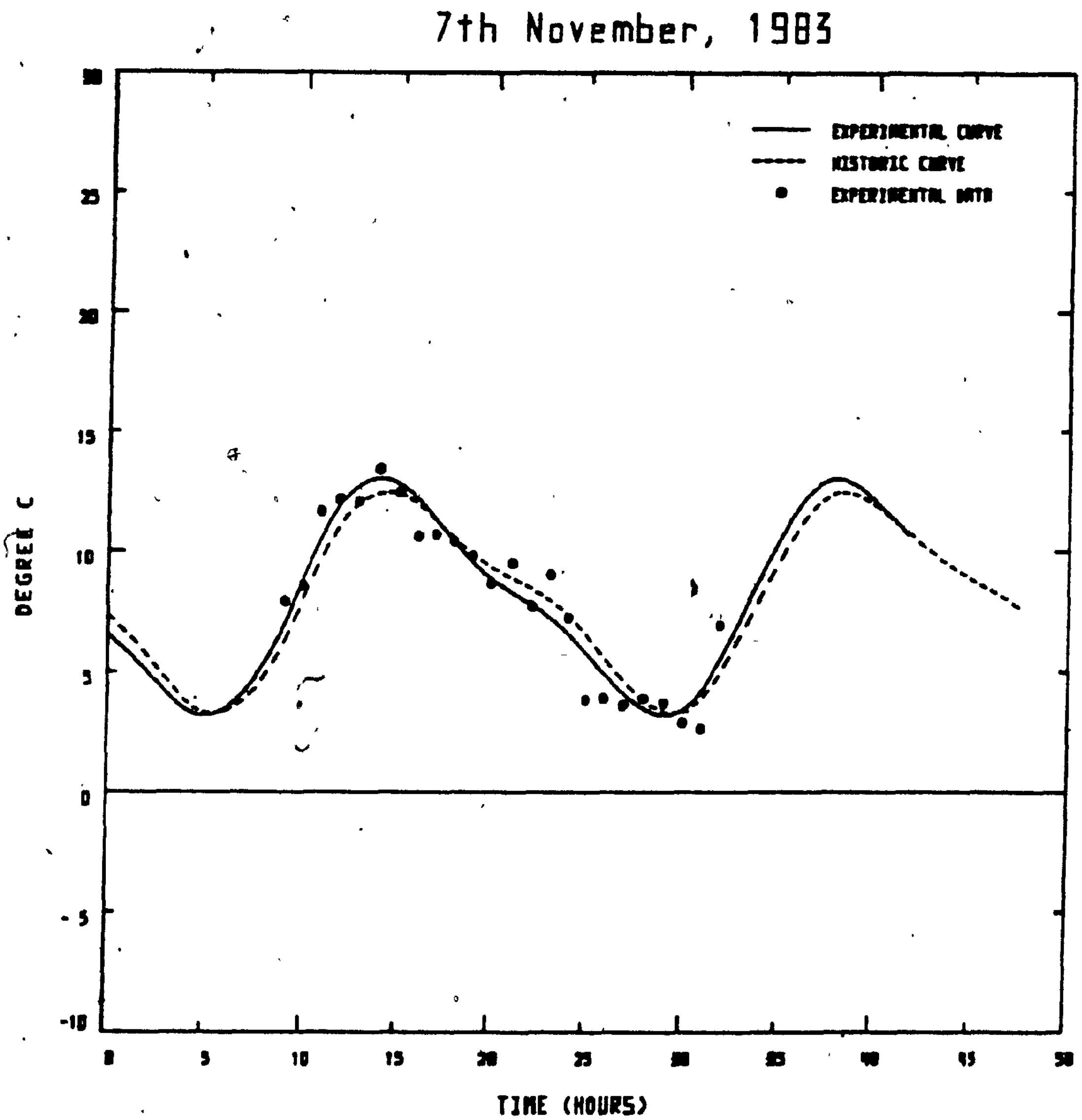


Figure 2.21 Comparison of improved historic curve and experimental weather data for 7th November.

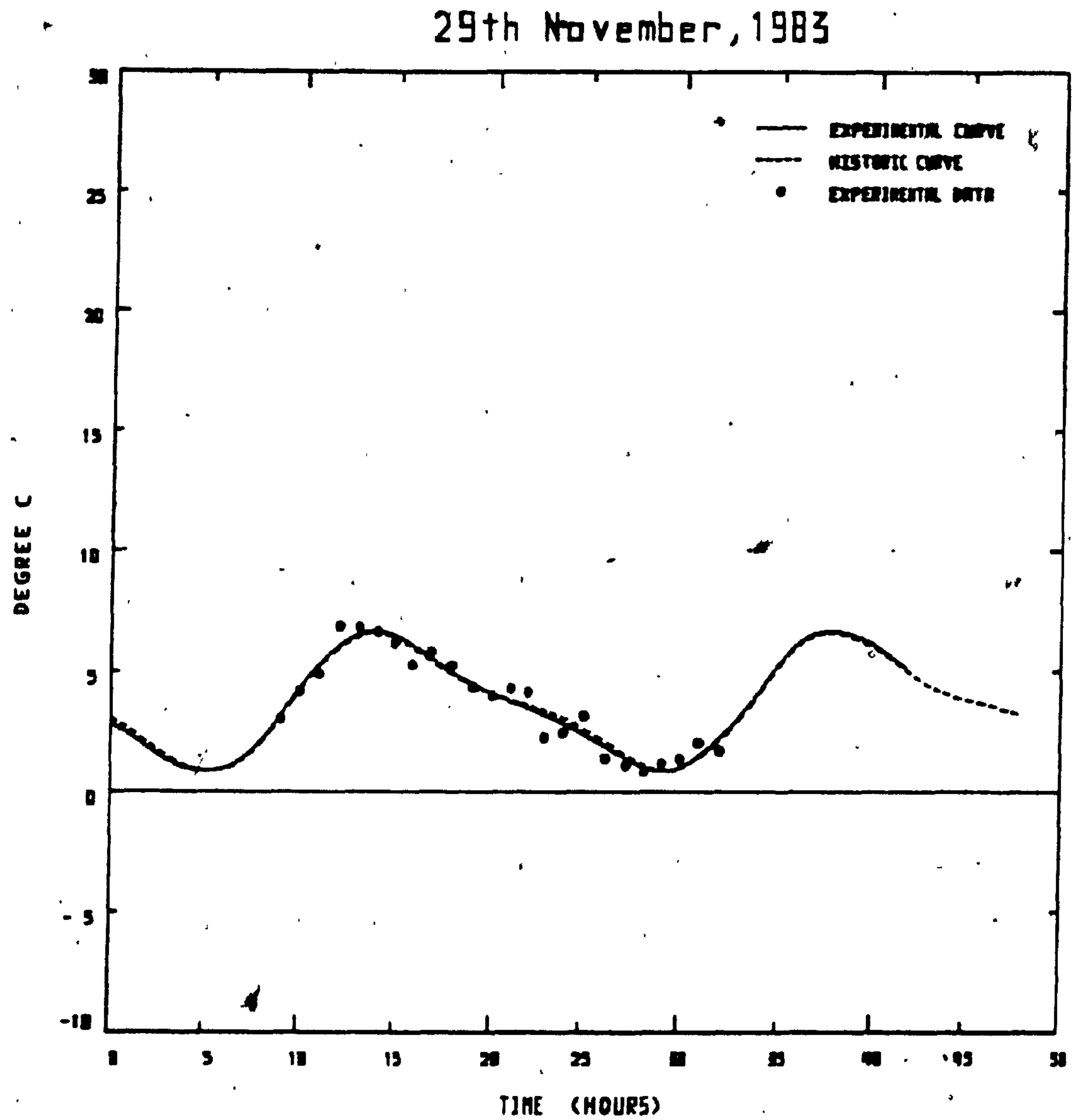


Figure 2.22 Comparison of improved historic curve and experimental weather data for 29th November.

2.4 Prediction Process

Before predicting the purchased energy requirements for the next day, we must decide whether or not we are in a normal weather regime. If a weather front is passing through when the prediction is made, the consequent change in average daily temperature will usually invalidate the prediction. We want to change our control strategy as soon as possible after the arrival of the weather front. On the other hand, we want to avoid changing strategy for a short term fluctuation in ambient temperature caused by a variation in wind direction or a cloud covering the sun, etc. A compromise must be made for the number of observations used to calculate the experimental ambient temperature curve. The more observations used, the less impact of fluctuations lasting only an hour or two on the curve obtained, but the longer the wait to be sure that a weather front has occurred. After a number of trials with the observed weather fronts, the following procedure was adopted. At each hour during normal weather an experimental curve is calculated, by varying C(1), C(2), C(3) and θ to minimize the sum of the squares of the deviations, using observations for the previous 11 hours, plus the current observation. This provides a reasonably accurate normal weather prediction for all of the data so far analyzed, but responds too slowly to fast moving weather fronts, which are typically of 3 to 4 hours duration in Montreal. To sense the weather front, we generate a 24 hour experimental curve from the first six of the twelve observations, and shift the historic curve to match the average of that experimental curve. The last six observations are then compared statistically to the shifted historic curve. The boundary between normal and abnormal weather is taken at a standard deviation of 1.6. This corresponds to an error of 1.5 °C for each of the 6 points. For higher standard deviations, we switch to the weather front strategy subroutine. For standard deviations less than 1.6, we shift the historic curve to a mean derived from all 12 observations and proceed with the predictions for purchased energy. The results of this process for a slowly moving weather front are shown in Fig. 2.23 to 2.25. The arrival of the weather front is sensed at time 20:00 in Fig. 2.24, 4 hours after it began.

The weather front strategy subroutine contains a section to check at each hour whether or not normal temperature patterns have been reestablished. This is done in two different ways consecutively. First, it may happen that the new normal temperature pattern has the same 24 hour average temperature as the pattern before the arrival of the weather front. To examine this possibility, we compare the last six observations statistically with the extension in time of the

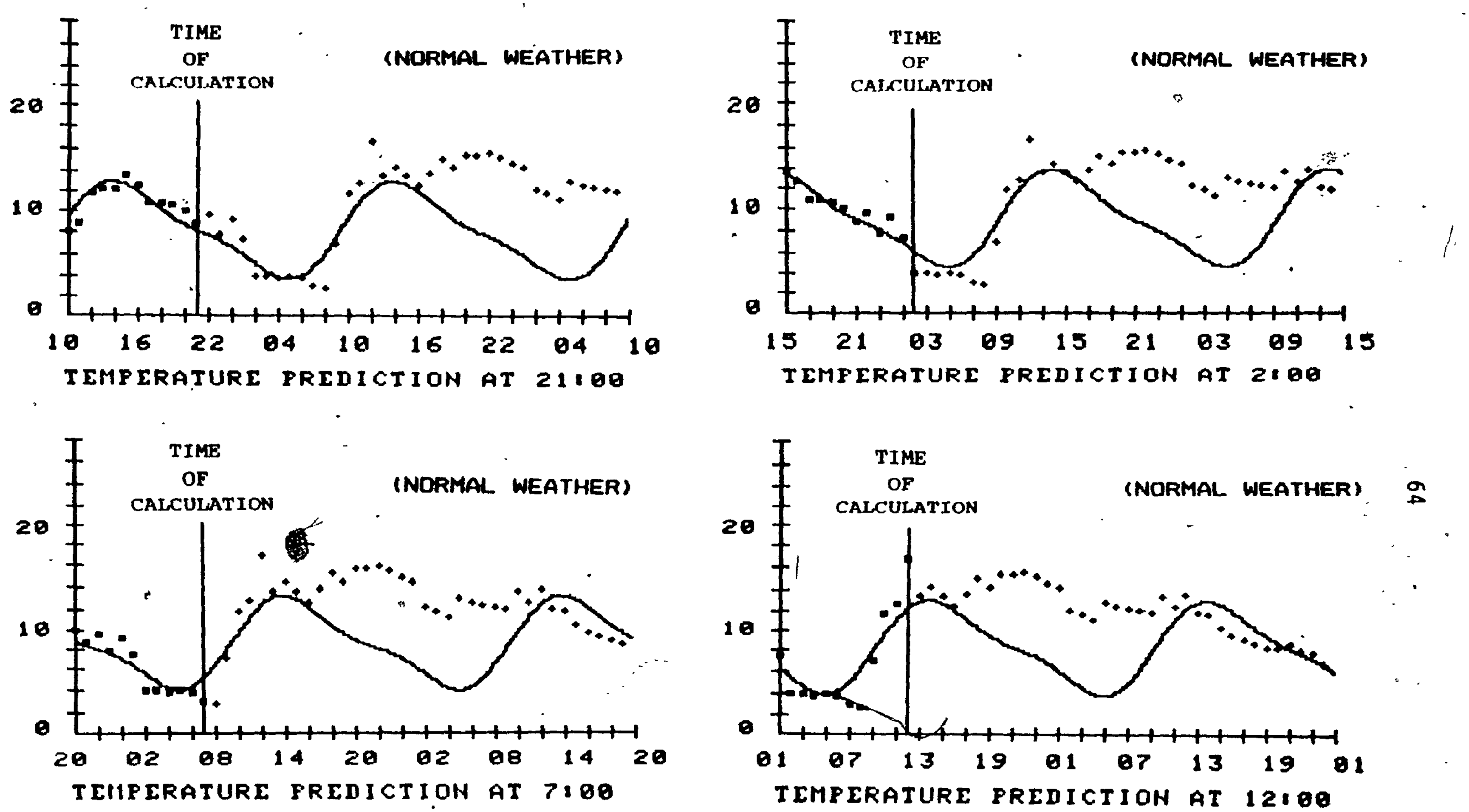


Figure 2.23 Temperature curves predicted from 21:00 Nov. 7 to 12:00 Nov. 8, 1983

■ Temperature observed before the calculation
\+ Temperature observed after the calculation
— Experimental curve derived from 12 observations previous to the calculation

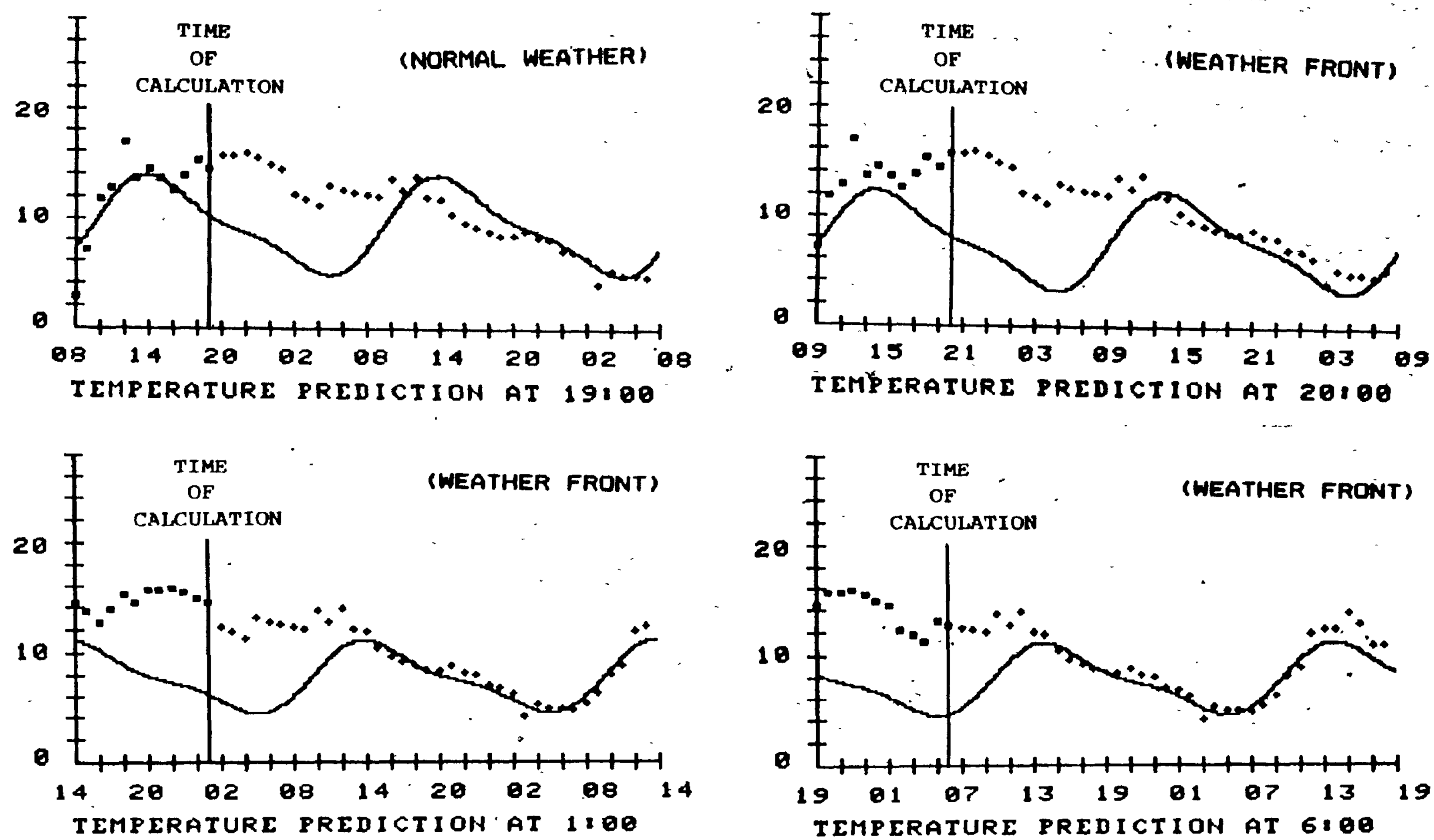


Figure 2.24 Temperature curves predicted from 19:00 Nov. 8 to 6:00 Nov. 9, 1983

- ■ Temperature observed before the calculation
- + Temperature observed after the calculation
- —— Experimental curve derived from 12 observations previous to the calculation

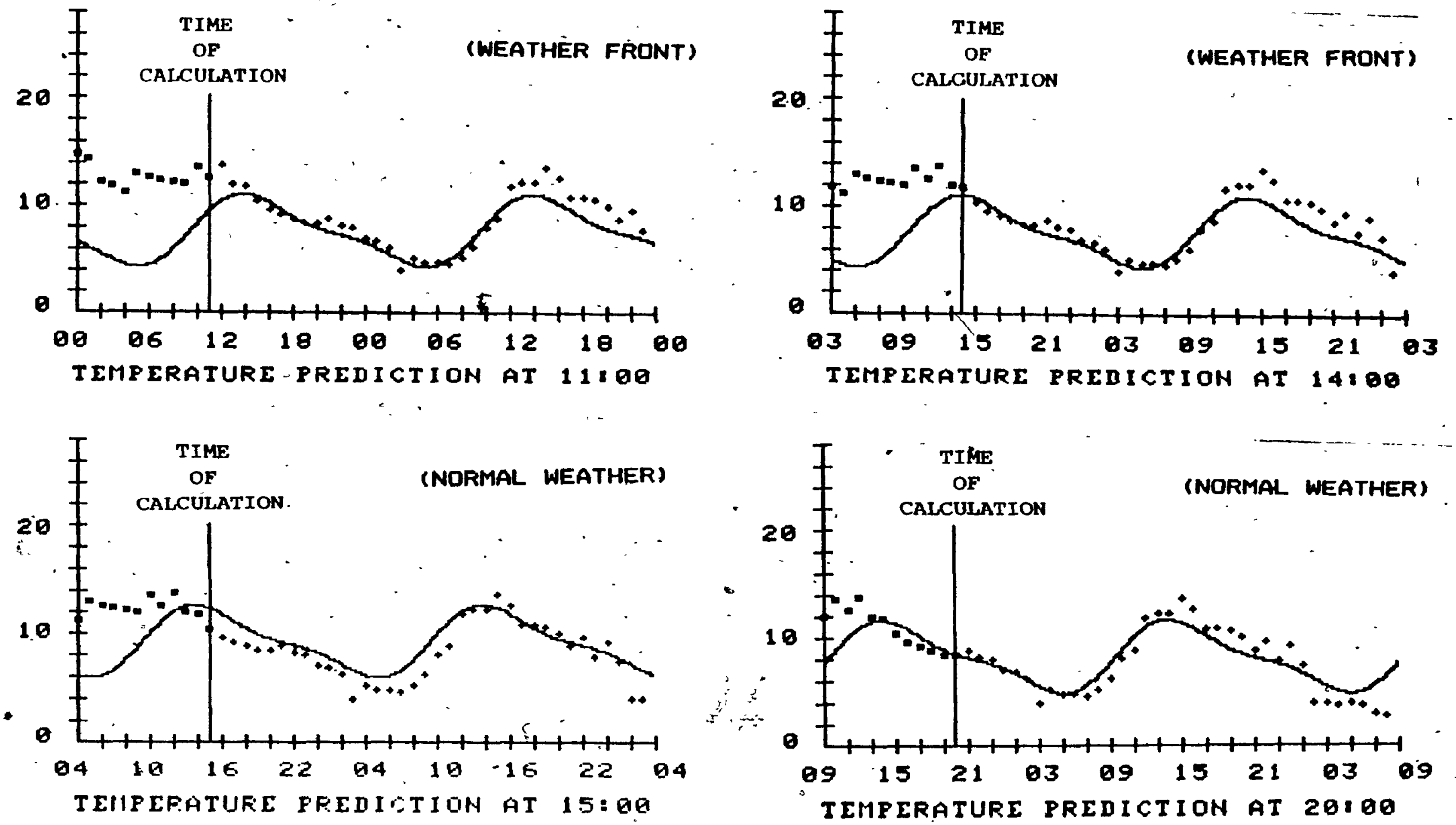


Figure 2.25 Temperature curves predicted from 11:00 to 20:00 Nov. 9, 1983

■ Temperature observed before the calculation
+ Temperature observed after the calculation
—— Experimental curve derived from 12 observations previous to the calculation

shifted historic curve used before the weather front. Again, the boundary between abnormal and normal weather is taken at a standard deviation of 1.6. If $\sigma < 1.6$, we return to the normal weather routine, using the same historic curve. If $\sigma > 1.6$ we must check for a return to a normal temperature pattern at a different 24 hour average temeprature. For this calculation, we calculate an experimental 24 hour curve from the previous 12 observations, (i.e. during the weather front) using least squares regression to obtain new values for C(1), C(2), C(3) and Θ. The historic curve is then shifted to the average of this experimental curve. A statistical analysis then follows, but in this case for 12 previous observations. The use of only 6 observations here could lead to a premature strategy change, since the temperatures during the passage of a weather front generally change slowly either up or down, and could match the slope of the historic curve during a 6 hour period. We need a nearly sinusoidal variation of the slope to be sure that normal weather has returned. The criterion for normal weather is again $\sigma < 1.6$. If that ocuurs, we resume the normal weather routine with the historic curve shifted to the new 24 hour average temperature. In the example shown in Figs. 2.24 and 2.25, the passage of the weather front lasted 21 hours. The return to the normal weather routine was by the first method at the same average temperature, only 3 hours after the exit of the weather front. For a case with a shift of the average temperature, the return could be slower, up to a maximum of 12 hours. However, there is not as much urgency to shift strategy at the end of a weather front as at the beginning, since the weather front strategy will match the new normal weather strategy reasonably well in most cases.

The prediction subroutine is listed in Appendix C. It includes a section to display the results graphically on the monitor, which was used to generate Figs. 2.23 to 2.25. It was checked experimentally for a total of 3 months, discontinuously between September and December 1983 and between August and November 1984. In most cases, the passage of a weather front was detected with 4 or 5 abnormal observations.

CHAPTER 3

MODEL FOR THERMAL FLOWS IN A BUILDING

3.0 Introduction

To carry out predictive control properly, we need to calculate the delayed response to any heating or cooling action available to the computer: viz; increasing or reducing the ventilation rate; turning the heater on or off (or changing the heater power); and turning the chiller on or off. Each of these actions may change the room temperature expected at the critical times on the next day when the purchase of heat or cooling is expected. To calculate the delayed response, we need information about the thermal inertia and the thermal losses of the building (or zone for a multiple zone building). This must be accurate enough to predict the future room temperature to within 1 degree Celsius. The intentions of the designer, as read from drawings will not be accurate enough for the thermal losses, since few buildings are finished as designed, and settling and repairs can change the thermal resistance of walls and windows. The thermal inertia of the building will depend in part on the mass of the furnishings.

installed, which will change periodically. Thus we need a model for the losses and inertia of the building which can be updated according to measurements of the actual situation, as built and as operated. We prefer a model where the update can be handled automatically by the computer, with low cost sensors. This led us to investigate models where the inertia and loss parameters can be inferred from the periodic temperature measurements required in any case for the control function of the computer program, i.e. from a series of measurements of room and ambient temperatures.

The method chosen also helps to alleviate another problem. For simple buildings, we would like to use only one indoor thermometer, to minimize calculation time and computer memory requirements, as well as sensor costs. In general, it will be impossible to locate that thermometer so that it reads the average temperature for the indoor air in contact with every exterior wall of the building. In most buildings, both vertical and horizontal temperature gradients are larger than 5 degree Celsuis on many days of the year. The thermometer cannot be placed where it will interfere with occupant traffic. In addition, that thermometer may be poorly calibrated. However, if all of the control decisions are taken in terms of the actual temperatures read, wherever the indoor and outdoor thermometers are placed, we can adjust the inertia and loss constants of the model to compensate for the difference between those readings and the average temperature that would be used in a priori calculations of the heat losses. In any case, we can only check the calculations against the recorded temperatures. Thus we need to predict the temperatures at the position of the sensors used, not at some arbitrary spot corresponding to average room or ambient temperature over all the walls and roof of the building. The inertia and loss constants derived from the temperature measurements and our model will not be "accurate" in terms of the average room temperature. That is of little consequence here, because the control decisions are to be made according to measurements by the actual thermometers as set in place. There is no need to predict average room temperature at all: we need only to ensure that our predicted temperatures match later mesurements, by varying parameters in the model until they do. After a few weeks of monitoring, parameters accurate enough for the control program are obtained.

The model used is a simplified version of the one used by Kerr [13], [14], [15] and by Shapiro [22] to analyse the measurements taken at the La Macaza solar house and the B.P. greenhouse. The analogy between Ohm's Law, $\Delta V = IR$ and the linear heat flow equation $\Delta T = qR$, which forms the basis for the definition of "thermal resistance" is shown in Table

3.1. We use an electric circuit analogy to the heat flows, rather than the thermal differential equations, in order to utilize electric circuit theorems, and to have a standard graphical representation of the thermal circuits. The solution should find applications in the design of solar buildings as well as in the predictive control of office buildings. Therefore, we include the solar input in this description of the model, even though there was none in the preliminary experiments done for this thesis.

3.1 Calculation Model

Solar radiation enters a building through windows and is absorbed on various surfaces (e.g. furniture and walls etc.) after passing through the air layer. Part of the energy is absorbed in the surface, and the rest reflects. Most of the reflected energy is absorbed by other surfaces. The heat transmission between the room and the outside air depends on the U value of the wall. Fig. 3.1. shows a typical heat flow diagram for an office. The analagous electrical circuit model is shown in Fig. 3.2., with the following assumptions:

1. 1-dimensional, linear and steady state heat flow in each component.

$$q = U * A * \Delta T$$

$$R_{elect} = \frac{V1 - V2}{I} \quad \Longleftrightarrow \quad R_{thermal} = \frac{T1 - T2}{q}$$

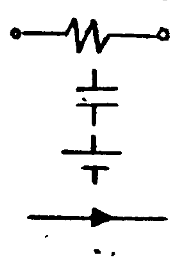
With I = Charge/Time $\qquad\qquad$ q = Heat/Time

C = Charge/V (store charge in C) $\quad \Longleftrightarrow \quad$ C = Energy/T (Store heat in C)

Thus stored energy

Not analagous

$$E_c = 0.5 * C * V_c^2 \qquad\qquad E_c = \int q_c \, dt = C \, \Delta T_c$$



Electric	Thermal	
R	R	Resistance
C	C	Capacity
V	T	Temperature
I	q	Heat flow

Table 3.1 Electric circuit analogy to the thermal flows

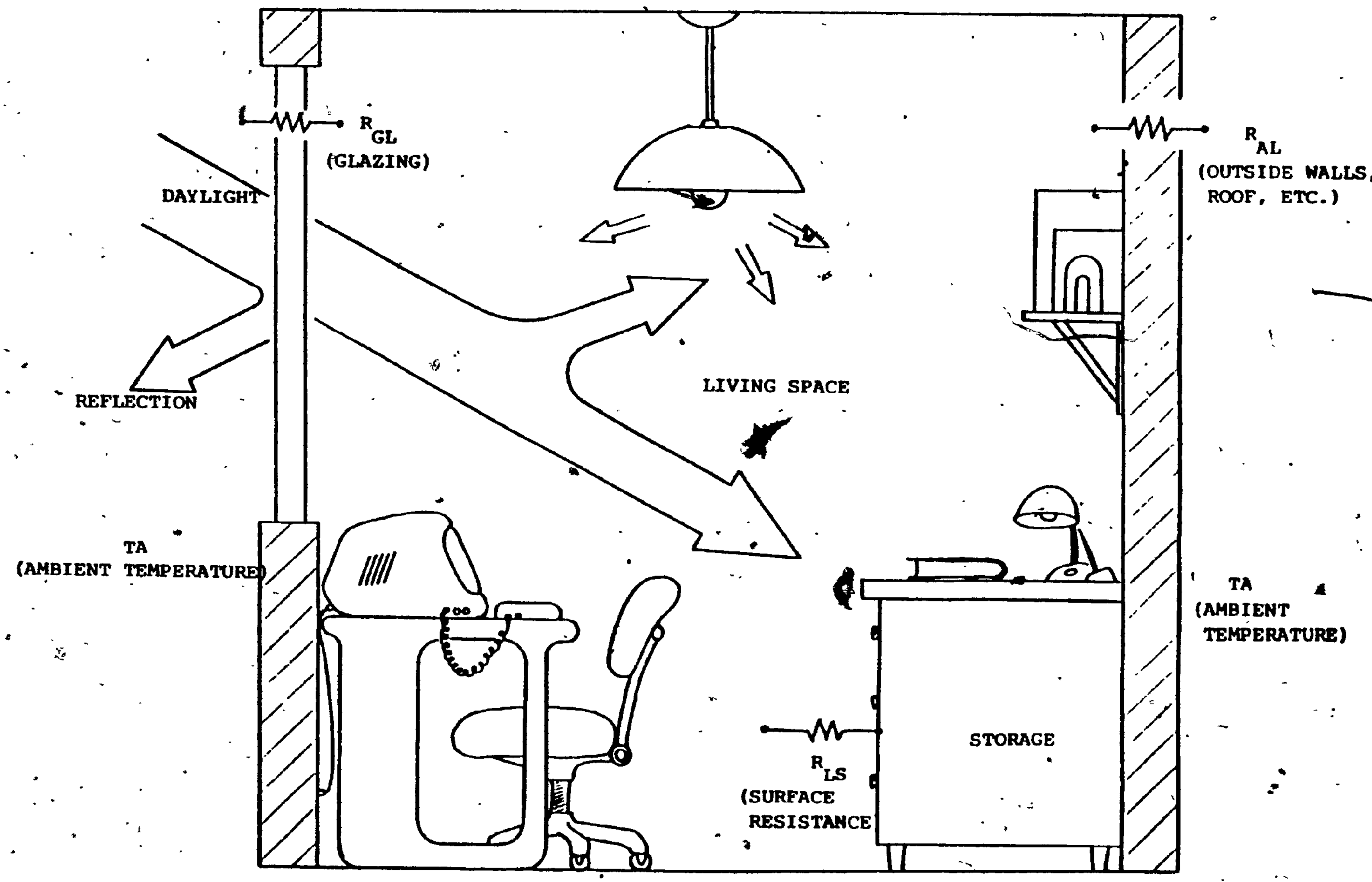


Figure 3.1 Thermal flow diagram for an office

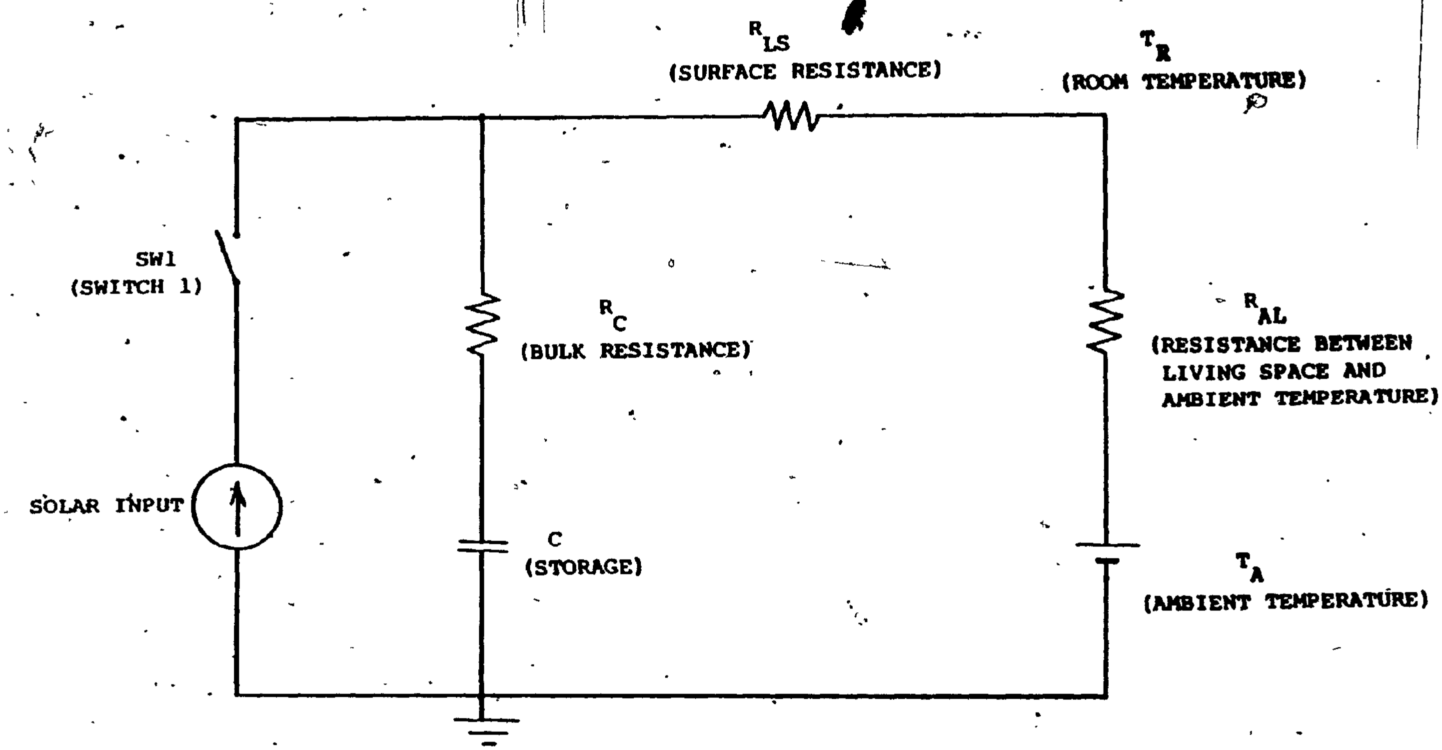


Figure 3.2 Electric circuit model for thermal flows in an office

Where: q = Heat flow through wall or ceiling, etc. (Watt)

U = Effective heat transfer coefficient of wall, etc. (W/m^2-K)

A = Surface area of wall or ceiling, etc. (m^2)

ΔT = Temperature difference (^oK)

2. The storage capacity and U values are not functions of temperature.
3. The ground potential (i.e. zero for arbitrary ambient temperature scale) is taken below the coldest temperature ever observed at this particular location.
4. Internal gains and space heating are constant for each hour of the calculation.
5. The calculation is only for normal weather.

Part of the solar energy in Fig. 3.2., penetrates the thermal storage C by conduction through the bulk resistance of the storage R_C. After absorption and conversion to heat, another part of the solar energy reaches the living space by conduction, convection and radiation through the resistance R_{LS} of the storage surface and the air film beyond it. Simultaneously, heat is lost from the living space to the outside through the glazing (R_G), walls R_W) and roof (R_R). R_{AL} is the summation of R_G, R_W and R_R in parallel. Shapiro [21] modelled the solar input as a square wave constant current source using switch SW1 to turn the solar source on at dawn and off at dusk and to change from the daytime average ambient temperature to the nighttime average temperature. In addition, a program (S.U.N.N.Y.) was developed to calculate the extreme dawn and dusk temperatures for clear day. That program requires the orientation and area of the glazing for input, to calculate the solar intensity. By using this square wave input to predict the extreme temperatures for clear design days, designers can quickly decide whether overheating will occur, and change their glazing or storage design as required, since the solutions for the temperatures are simple single exponential buildups or decays. The main disadvantages for the present task are that the times when maximum and minimum temperatures occur are shifted by several hours, and that several iterations are required before a stationary solution is reached.

In order to predict room temperature accurately as a function of time, realistic solar intensities and ambient temperatures must be used. Square wave approximations are not useful for predictive control.

The time dependent ambient temperature is expressed in the Fourier series form which was discussed in Chapter 2.

$$TA(t) = C(1) + C(2) * SIN(w*t + 3*\Theta) + C(3) * SIN(2*w*t + \Theta)$$

Where: TA(t) = Ambient temperature at time t.

$C(1)$ = Average temperature of previous day.

$C(2), C(3), \theta$ = Curve fitted coefficients from past weather data.

$w = 2 * \pi /24$

For a vertical window facing due south the solar input is assumed to be a half-sine wave in Ref [16] and [17] placed between sunrise and sunset for each day.

$$S(t) \begin{cases} S1 * SIN[w1*(t - tsr)] & ; \text{daytime} \\ 0 & ; \text{night time} \end{cases}$$

where : $w1 = \pi/ (tsr - tss)$

tsr = Sunrise Time, in hours.

tss = Sunset Time, in hours.

for a clear day, for solar noon,

$$S1 = \sum_j I * COSi_j * \tau_j * A_j$$

where:

I = Solar Intensity (0.9 kW/m^2)

i_j = Incident angle between the direct beam solar radiation and the normal to the glazing j.

τ_j = Transmission factor for glazing j.

A_j = Area of glazing j.

In order to simulate the effect of internal heat sources added to the room, a heat source is included in the circuit (Fig. 3.2). The modified circuit, as shown in Fig. 3.3.,

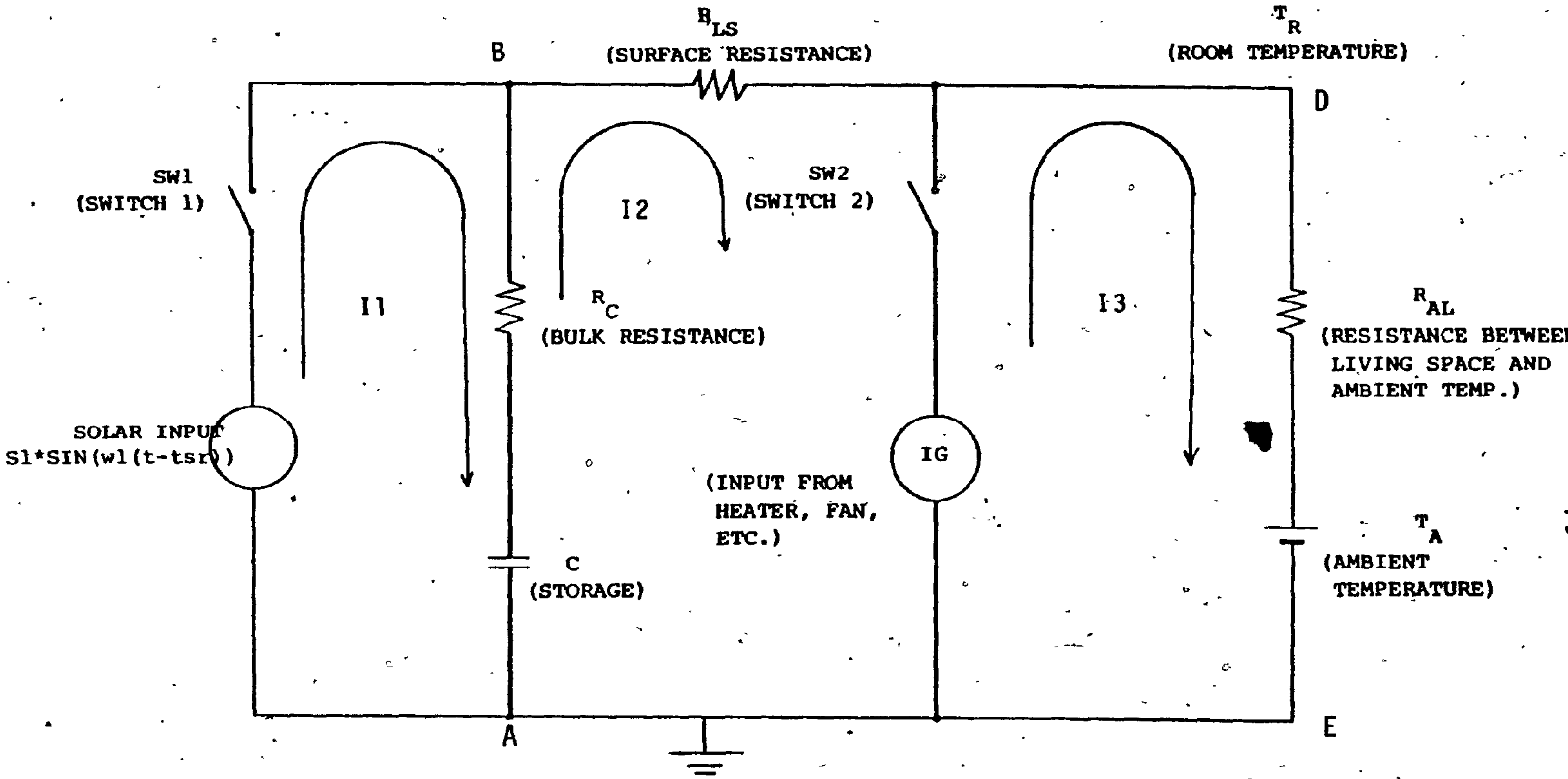


Figure 3.3 Revised thermal circuit model for an office

$$I2 = A * e^{-\alpha t} + \alpha * S1 * B * \left\{ \frac{SIN[w1*(t - tsr) + \phi_1 - \phi_2]}{\sqrt{(\alpha^2 + w1^2)}} \right\}$$

$$- w * \alpha * C * \left\{ \frac{C(2) * SIN(w*t + 3*\theta + \phi_3)}{\sqrt{(\alpha^2 + w^2)}} + \frac{2 * C(3) * SIN(2*w*t + \theta + \phi_4)}{\sqrt{(\alpha^2 + (2*w)^2)}} \right\} \quad (3.2)$$

Where:

A is obtained essentially as a boundary condition, by substituting equation 3.1 in the constraint equation, and eliminating I2 and I3 with the current measurements for TR and TA, as shown in Appendix D.

$$\alpha = \frac{1}{(R_C + R_{LS} + R_{AL}) * C} = \frac{1}{\text{Time constant}}$$

$$B = \sqrt{(R_C * C * w1)^2 + 1}$$

C(2), C(3), θ = Curve fitted coefficients from past weather data

$$\phi_1 = TAN^{-1}[R_C * C * w1]$$

$$\phi_2 = TAN^{-1}\left[\frac{w1}{\alpha}\right]$$

$$\phi_3 = TAN^{-1}\left[\frac{\alpha}{w}\right]$$

also includes switch SW1 and SW2. SW1 closes between sunrise and sunset, when solar radiation is an input source; hence SW1 reamins open at night time. SW2, on the other hand, closes whenever the internal sources are on.

Three operating modes are easily deduced from the circuits:

3.1.1 Charging mode (Mode 1)

With SW1 and SW2 both closed, the circuit is in the charging mode. The period of solar charging is between sunrise and sunset. Room temperature can be determined by the following expression:

For loop ABDE $\Sigma V = 0$

$$\frac{1}{C} \int (I2 - I1) * dt + R_C * (I2 - I1) + R_{LS} * I2$$

$$+ R_{AL} * I3 + TA(t) = 0 \qquad (3.1)$$

Constraints

$$I1(t) = S1 * SIN[w1*(t-tsr)]$$

$$I3(t) = IG + I2(t)$$

By solving these equations, as explained in Appendix D, the heat flow through the walls & roof can be expressed in terms of the capacitor output current:

$\phi_4 = TAN^{-1}[\frac{\alpha}{2*w}]$

$w1 = \pi/(tsr-tss)$

$w = 2 * \pi/24$

IG = Internal heat gains + auxiliary heating.

I2 = Heat flow through the room.

The Heat flow equation can be expressed in terms of a response function [9], [10] by:

$$I2(t) = CA(t) + SI(t) + TT(t)$$

or

$$I3(t) = IG + CA(t) + SI(t) + TT(t)$$

Where :

CA(t) = time response function due to thermal mass of building.

SI(t) = Time response function due to solar input.

TT(t) = Time response function due to ambient temperature.

Room temperature is calculated by:

$$TR(t) = (I2(t) + IG) * R_{AL} + TA(t) \qquad (3.3)$$

3.1.2 <u>Discharing or Charging (Mode 2)</u>

With SW2 closed and no solar input (SW1 open), the capacitor (thermal mass) is either discharging, charging or in an equilibrium mode. If the internal source generates an equal amount of heat to the heat loss through the wall and C is at room temperature, an equilibrium state is obtained and room temperature remains constant. If the internal source is larger than the heat loss, charging will occur. Otherwise, the capacitor will discharge, keeping room temperature higher than ambient temperature. All these states are represented by the following equations:

For loop ABDE, $\Sigma V = 0$

$$\frac{1}{C} \int I2 * dt + R_C * I2 + R_{LS} * I2 + R_{AL} * I3 + TA(t) = 0 \qquad (3.4)$$

Constraint:

$$I3(t) = IG + I2(t)$$

With I2 negative when the capacitor is being charged by part of IG, and I2 = 0 when IG = I3, at equilibrium.

The heat flow out of the capacitor with no solar input is found to be:

$$I2 = A * e^{-\alpha t} - w * \alpha * C * \left\{ \frac{C(2) * SIN(w*t + 3*\theta + \phi_3)}{\sqrt{(\alpha^2 + w^2)}} + \frac{2 * C(3) * SIN(2*w*t + \theta + \phi_4)}{\sqrt{(\alpha^2 + (2*w)^2)}} \right\} \qquad (3.5)$$

Room temperature is expressed as:

$$TR(t) = (I2(t) + IG) * R_{AL} + TA(t) \qquad (3.6)$$

3.1.3 Discharging mode (Mode 3)

With both SW1 and SW2 open, the thermal storage is in the discharging mode. The discharge current is obtained from the following equations:

Consider loop ABDE, $\Sigma V = 0$.

$$\frac{1}{C} \int I2 * dt + R_C * I2 + R_{LS} * I2 + R_{AL} * I3 + TA(t) - = 0 \tag{3.7}$$

Constraint:

$$I3(t) = I2(t)$$

As shown in Appendix E, The heat flow I2(t) can be expressed as:

$$I2 = A * e^{-\alpha t} - w * \alpha * C * \left\{ \frac{C(2) * SIN(w*t + 3*\theta + \phi_3)}{\sqrt{(\alpha^2 + w^2)}} + \frac{2 * C(3) * SIN(2*w*t + \theta + \phi_4)}{\sqrt{(\alpha^2 + (2*w)^2)}} \right\} \tag{3.8}$$

and

$$TR(t) = I2(t) * R_{AL} + TA(t) \tag{3.9}$$

With these equations we can calculate room temperature for the different operating conditions, on a clear day with normal weather. Since the internal source can change from hour to hour, we must do an hour by hour calculation. When the operating mode changes, we must calculate a new A for the capacitor discharge term for each hour. A least squares comparison with the measured hourly temperatures can give values for and C and then A and B. The resistances and capacitance thus obtained can be used on partly cloudy days, but the solar input for the calculation must be changed each hour to correspond to the measured value. To avoid this complication, the preliminary measurements done for this thesis were obtained with a windowless test hut. For on line predictive control, some assumptions must be made about internal gains during the prediction period. In office buildings, these are reasonably well known, or else one could use those that occurred during the last recorded day. The internal gains should be changed seasonally, since, in this model, fan cooling for ventilation amounts to a negative internal gain. For simplicity, in the validation experiment on Nov. 8 discussed in chapter 5, the fan was kept off.

CHAPTER 4

EXPERIMENTAL APPARATUS AND THE PREDICTIVE CONTROL PROGRAM

4.0 Introduction

Low cost predictive control requires both simple models for the building thermal inertia and for the ambient temperature prediction, to enable the use of microcomputers, and inexpensive, reliable hardware for temperature sensing and control of the H.V.A.C. system. In order to determine the feasibility of a full scale system, and to develop and validate most of the elements of a predictive control program, a partial experiment was carried out in a test hut on the roof of the Centre for Building Studies. A baseboard heater, a window type air conditioner and a site fabricated fan ventilator were controlled with a predictive program written for an Apple II+ computer. Internal gains were simulated with light bulbs. To avoid the complications of large fluctuations in the solar input on partially cloudy days, the test hut was set up with no windows, Thus, a simpler thermal inertia model than that of Chapter 3 could be validated with better certainty, allowing a more reliable comparison to a calculation for the energy that would have been consumed with normal, non predictive controls during the same time period. Budget restrictions did not allow building a second test hut for a side by side comparison.

4.1 Experimental Equipment

The test hut (Fig. 4.1, 4.2 and 4.3) had been constructed on the roof of the Centre for Building Studies for a previous study of the effects of window to wall area ratio on energy consumption, in 1980 [6]. The intent was to simulate an outside office with one wall exposed to the weather and the other five sides contained in a thermostatically controlled cavity, to simulate the thermal environment of the neighbouring rooms in an office building. With no circulation of air, all the heat losses from the test room are through a single wall, easy to measure and to calculate. For this experiment, 293 Kg (645 lb.) of concrete blocks were also located inside the test chamber, to increase the thermal storage capacity to correspond to concrete construction, and allow a reasonable amount of preheating or precooling, necessary for predictive control.

Temperatures were measured with YSI Series 400 thermistor probes manufactured by Yellow Spring Instrument Co. Inc.. A total of 9 probes were used to measure temperature at different locations. The first two probes were used to measure ambient temperature, one with a tubular

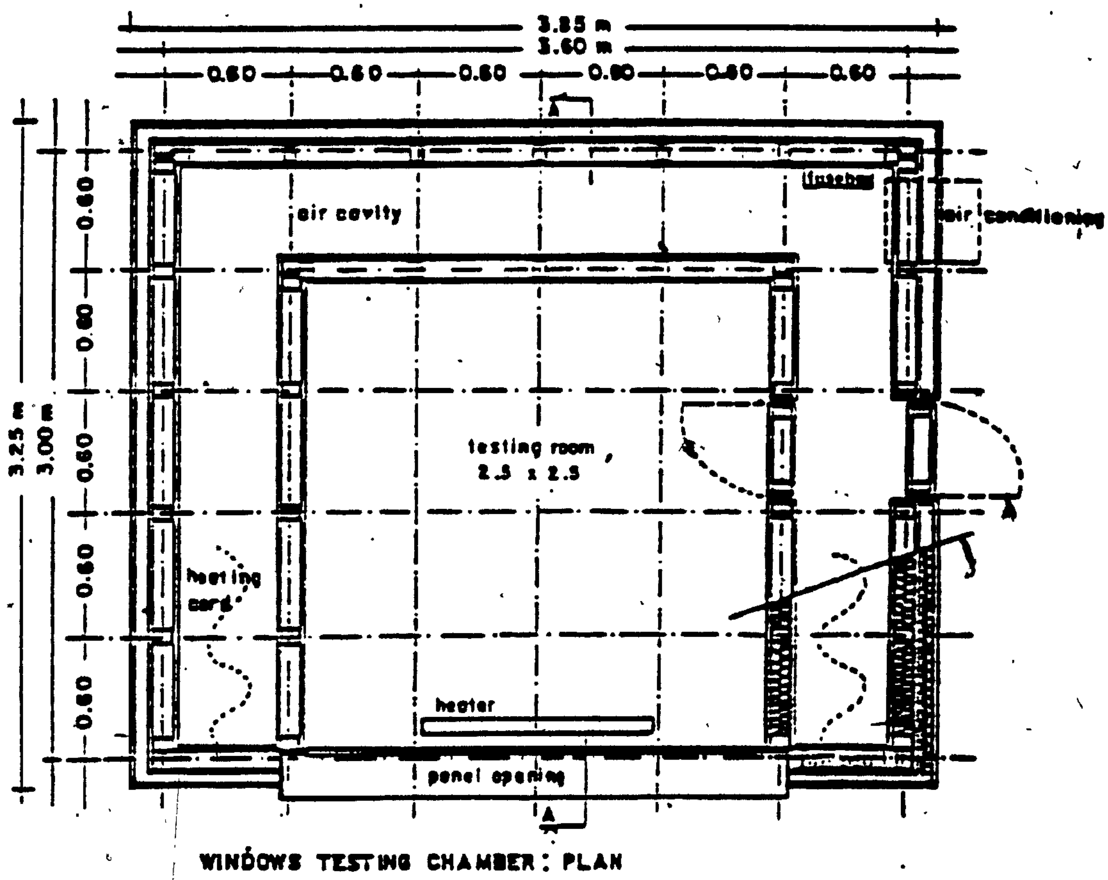
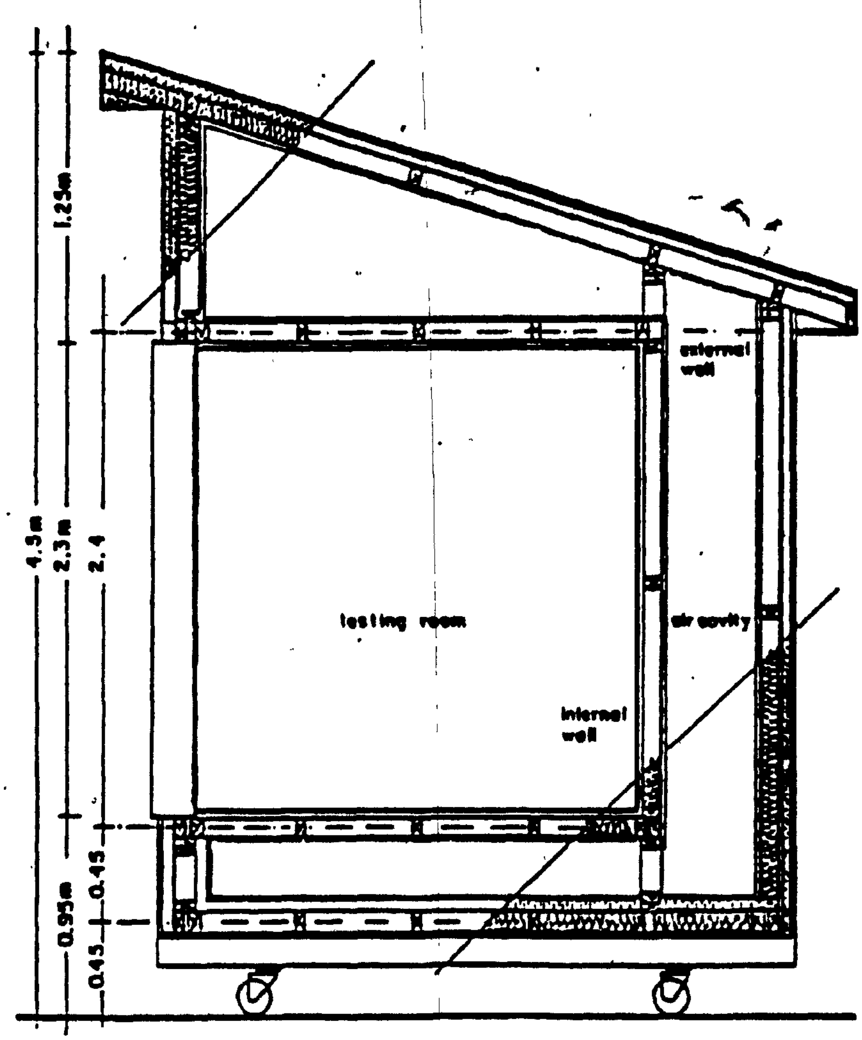


Figure 4.1 Horizontal section through the test hut



WINDOWS TESTING CHAMBER: SECTION A-A

Figure 4.2 Vertical section through the test hut

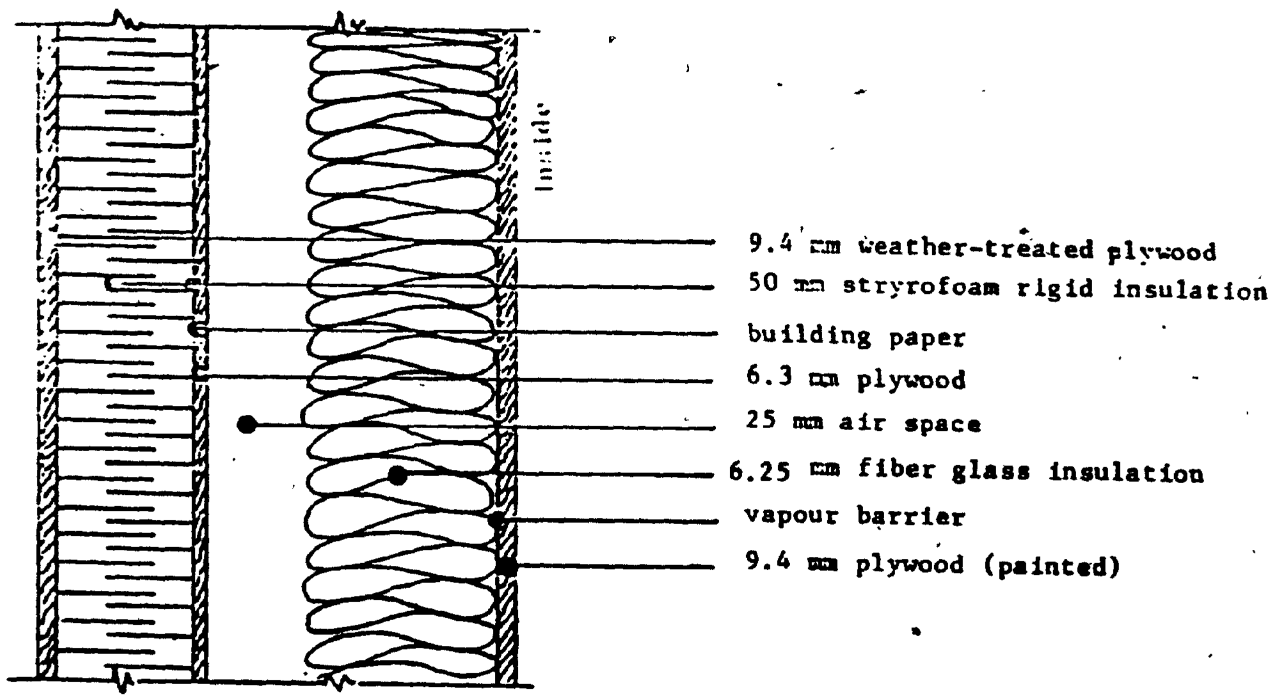


Figure 4.3 Vertical section through the external wall panel

radiation and wind shield, and one without a shield. Three other probes were placed diagonally across the room, to measure air temperature at different heights and depths. The cavity, concrete block storage surface, and outside and inside wall surface temperatures were also measured, to allow separate checks of the components of the thermal inertia model.

The probes were connected to a modified Gulton chart recorder, shown schematically in Fig. 4.4. An ice point instrument (KAYE Ice Point Reference) was used to check the zero point of the probes and amplifier.

The monitoring and control circuit in Fig. 4.4 contains three main parts: a Remote Control; a Chart Recorder with an electronic selector for the thermistors; and the heating and cooling Equipment Controller. The Remote Control, located in the Apple II+, was used to send signals to select different channels for either recording temperatures or controlling the heating and cooling equipment. The actual switches were located in the test hut.

To record a temperature, a reset signal (+5V) is sent from the amplifier (741) to the chart recorder to reset the selector to the first channel. Successive signals through the channel select line step the chart recorder output through the thermistors in order. When the desired channel

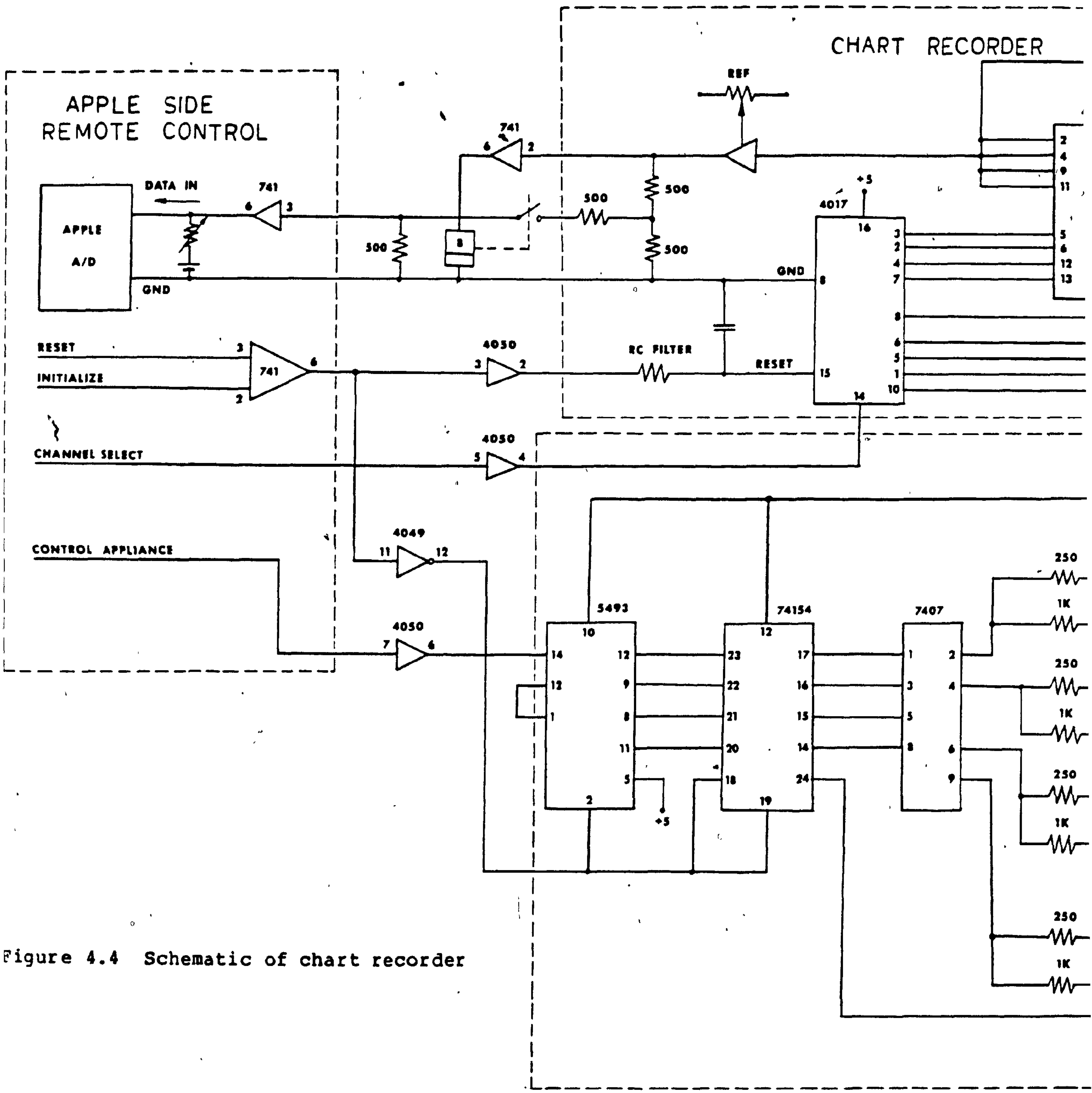


Figure 4.4 Schematic of chart recorder

1 of

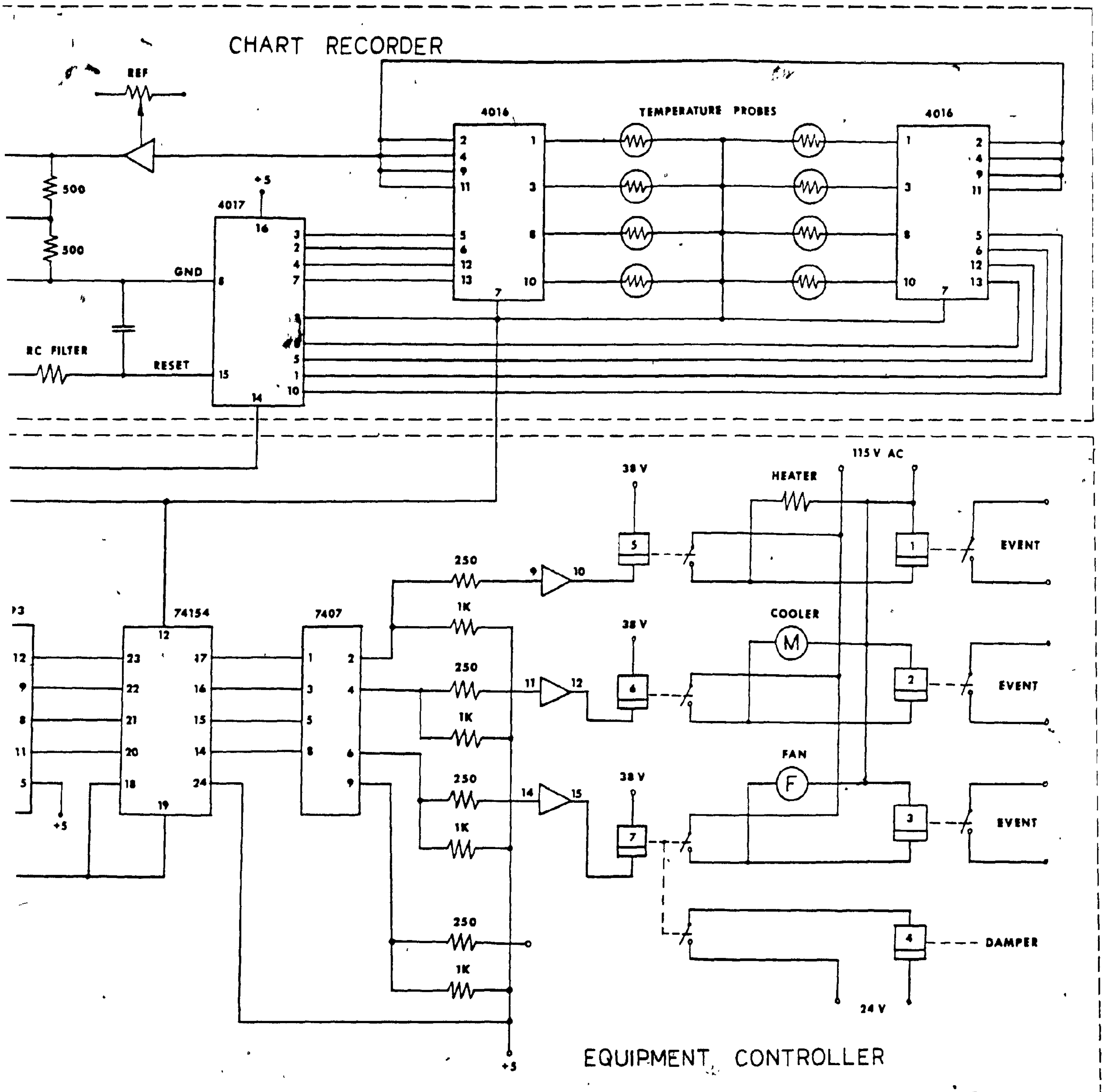


CHART RECORDER
REF
500
500
4017
+5
GND
RC FILTER
RESET
4016
TEMPERATURE PROBES
4016
115 V AC
38 V
HEATER
EVENT
COOLER
EVENT
FAN
EVENT
DAMPER
24 V
250
1K
74154
7407
+5
EQUIPMENT CONTROLLER

is reached, the analog digital converter is cleared and the thermistor voltage is digitized and routed to the proper memory file in the Apple.

A similiar procedure was used to control the heating and cooling appliances. An initialize signal (-5V) from the 741 amplifier turns all three appliances off. Seven pulses through the control appliance line turns on the heater. Fourteen pulses are used to turn on the air conditioner, and 21 pulses for the fan and damper.

A Rotron model MU2A1 fan was installed at the top right corner of the exposed outside wall, as shown in Fig. 4.5; with a precipitation shield on the outside, and a spring loaded damper to reduce infiltration when the fan is off. With the fan on, exhaust air was expelled through the electro-mechanical controlled damper shown in Fig. 4.6, located at the lower left corner of the exposed wall. The flow rate of the fan was measured in situ with a Datametrics Model 810L-M-DAX flowmeter. The measured flow rate was 19 l/s (40 CFM) $\pm$ 10% for different outside wind speeds.

The cavity between the inner and outer wall was kept at 20 °C by a Honeywell thermostat. It was heated by three 100 ft long heating cables suspended in loops from the ceiling to the floor. The 0.5 KW cables were manufactured by Heron Cable Industries Limited (Model ADkS-500-C1). The cooling was supplied by a 1465 Watt (5000 BTU/hr) window air conditioner. The model used was a Mastercraft-5000, manufactured by Canadian Tire Limited.

The heater for the test room was a 1500 Watt Mastercraft baseboard heater. The cooling equipment was an air-conditioner identical to that placed in the cavity, previously calibrated by El Diasty [6].

4.2 The On Line Control Program

Because of the RAM memory limitations of the Apple II+ computer, the Predictive Control Program is organized as five separate programs on a disk, written to RAM sequentially as required, and linked by common memory files, kept on the same disk. Files of all the monitored temperatures and the changes in the modes of operation of the H.V.A.C. system were kept on a second disk, to be used for analysis. The five major programs are : (a) The Initialization routine, used to reserve space for the common memory files on the disk, and to collect values for ambient temperature for the first 12 hours, for use in the first prediction (c.f. flow charts and program listings in Appendix E); (b) The Prediction routine , used to calculate the coefficient C(1) from the 12 hours of recorded ambient temperature, and to decide if the recent temperatures are

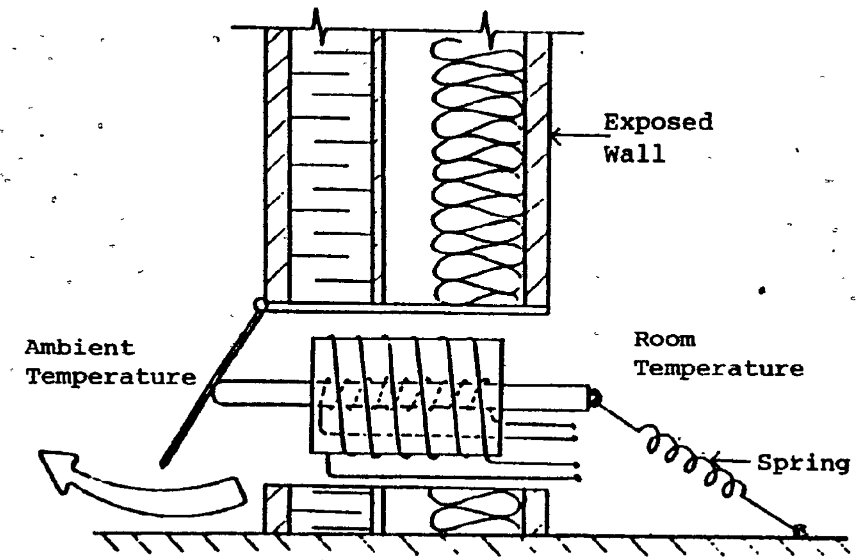


Figure 4.6 Cross section of mechanical controlled damper

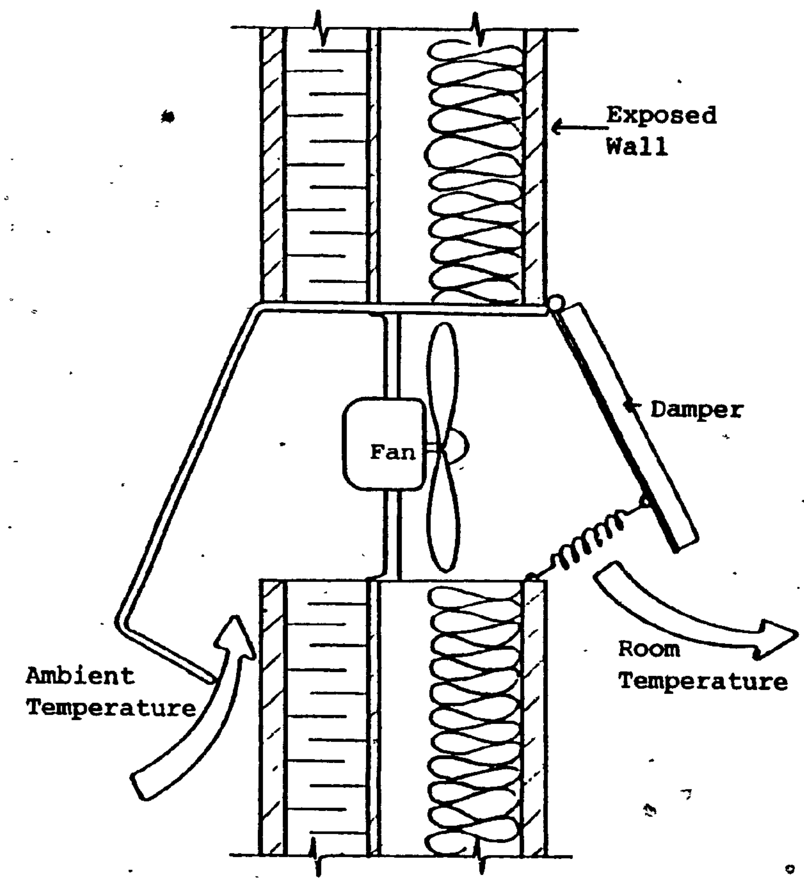


Figure 4.5 Cross section of fan

normal or abnormal; (c) The Normal Control routine used to request operation of the baseboard heater or air conditioner, should room temperature be outside the comfort zone, to calculate the amount of advance free heating or cooling required to prevent use of the baseboard heater or air conditioner in the 24 hour period previewed, to check if the use of free heating will entail the purchase of cooling later and vice verce, and revise the calculated amount of free heat or cool to be used accordingly, and to request action to move room temperature to the middle of the comfort zone with free heat or cool if none of the above actions were chosen; (d) The Abnormal Control routine, used to request action to move room temperature to the middle of the comfort zone with free heat or cool until a normal ambient temperature pattern reappears; (e) The Time Control routine, used to take the nine temperatures every 5 minutes, and store 15 minute averages, to exit to the Prediction routine every hour, to check every 5 minutes if the actions chosen in the Normal or Abnormal Control routines are feasible at that time, or should be delayed five minutes (e.g., if ambient temperature > room temperature, fan cooling is impossible), and to operate the baseboard heater or air conditioner if room temperature is outside the comfort zone at any 5 minute check.

4.2.1 Initialization

This routine is only used once, upon commencing on line predictive control, for a period between 11 and 12 hours long. Three files on disk 1 must have measured values before the Prediction and Normal Control routines can be used. These are: DATA1, which contains the last ambient temperature read and the time at which it was read; DATA2, which contains the 11 previous hourly ambient temperatures; and VARB, which contains the last room temperature read, the time at which it was read, C(1), the daily average temperature corresponding to the last 12 hourly ambient temperatures recorded, and C(2), C(3) and θ , taken from a list embedded in the code for the Prediction routine, in this case appropriate for each 2 week period at Montreal. For the first TA in DATA2, a single reading taken at startup is used. The other ten values are each an average of 4 measured ambient temperatures taken at the 45, 50, 55 and 60 minute marks for each hour. When DATA1 is filled at the end of Initialization, room temperature is also stored in VARB.

In addition, a fourth file is opened on disk 1 during Initialization. This is OPER, which will soon contain a code number for the mode of operation chosen for the H.V.A.C. system during the Normal or Abnormal Control routines, and the time required for operation in that mode, in the case of pre-cooling or pre-heating. The codes are: 0, which means take no action; 1, which means pre-cool; and 4, which means move room temperature to the middle of the comfort zone (i.e. the abnormal control path is in effect).

Ten files are reserved on disk 2, during Initialization. Each of the nine temperatures measured is stored in a separate file at 15 minute intervals, during the operation of the Time Control routine. The tenth file contains a coded history of the H.V.A.C. system operation. Whenever the mode of operation is changed, the time and the new mode of operation are stored. The codes are: 0, which means all H.V.A.C. components are off (i.e. heating with internal gains); 1, which means the fan was turned on; 2, which means the baseboard heater was turned on; and 3, which means the air conditioner was turned on.

The Initialization program is eliminated from RAM when it loads the Prediction routine from disk 1.

4.2.2 Prediction

The first task done in this routine is the calculation of C(1) from the twelve ambient temperatures stored in DATA1 and DATA2. This is done as described in chapter 2, by fitting the historical average curve to the 12 TA, and then taking the smoothed 24 hour average TA as C(1). Next, the last six TA are used to decide whether the temperature pattern is normal or abnormal, using $\sigma = 1.6$ as the criterion, as decribed in chapter 2. For normal weather, C(1) is stored in VARB, and the Normal Control routine is written to RAM from disk 1. For abnormal weather, the Abnormal Control routine is run.

4.2.3 Normal Control

The first step in this routine is to calculate the ambient temperature for 24 hours in advance using the Fourier series approximation. If the predicted TA will neither exceed BU, the balance point for cooling nor fall below BL, the balance point for heating during the next 24 hours, we calculate a predicted room temperature for that period, using the circuit analogy and the best fit Resistances and Capacitor, embedded in the code at line 120. If the average predicted room temperature will be above CM, the temperature at the middle of the comfort zone, we apply fan cooling if possible until the future average reaches CM.

If cooling will be required in the next 24 hours, the amount required is calculated from the hourly temperature difference across the building envelope and R_{AL}, the "as built" thermal resistance of the envelope, assuming that the air conditioner would operate as required by the load. Next the time required for fan pre-cooling to supply the same amount of cooling starting as soon as possible and using ambient air at the hourly predicted temperatures is calculated. If pre-cooling will cause a demand for baseboard heating in the next 24 hours, the amount of pre-cooling is reduced to avoid the heating expense. The reason for using a prediction for 24 hours is to ensure that both the highest and the lowest ambient temperatures are included, so that this check and the converse one for pre-heating are meaningful. The pre-cooling operation mode code and the adjusted time for pre-cooling are stored in OPER.

If heating will be required in the next 24 hours, the fan is turned off, to allow internal gains to heat the room for the current hour. If this amount of pre-heating exeeds the amount required later, fan cooling will be applied after the next hourly prediction. The operation mode code 0 is stored in OPER. At exit from each of the branches of Normal Control, the Time Control program is called from disk 1.

4.2.4 Abnormal Control

The control strategy chosen for the period of time when a weather front is passing through is quite simple. Room temperature is kept close to the middle of the comfort zone with fan cooling or internal gains (if possible) until the ambient temperature pattern returns to normal. Then Normal control is resumed with a new C(1) corresponding to ambient temperature after the weather front. In most cases, this Abnormal Control strategy will amount to opposing the change induced by the weather front with free heat or cool: i.e. we heat during a cold front and cool during a warm front. The compensation (if any) at the restart of Normal Control will also usually be done with free heat or cool. Occasionally, however, this Abnormal Control strategy will not be optimal and will result in some purchased heat or cool. However, this cannot be predicted in advance, because we don't know in advance what the 24 hour average ambient temperature after the weather front will be. More complex control strategies would also miss the optimal action occasionally, so a simple strategy was chosen. The steps taken in Abnorml Control are correspondingly simple. Code 4 is stored in OPER, and the Time Control program is called from disk 1 to create the appropriate signals to turn the fan on and off.

4.2.5 Time Control

Signals to operate the data acquisition system and to turn the appliances on and off are generated in this routine, at five minute intervals. The first step is to read the OPER file, which contains the operation codes and durations selected during the Normal and Abnormal Control routines. Next the nine temperatures are read from the

D.A.S. and the time is taken from the Apple Clock board in the Apple. Every 15 minutes, the temperatures are averaged and stored on disk 2, and the prediction routine is called at the end of each hour.

If room temperature is outside the comfort range, either the baseboard heater or the air conditioner is turned on for five minutes, and either Code 2 or Code 3, plus the time are files on disk 2. This action has first priority, and continues until either room temperature reaches the comfort zone or the hour is up. With room temperature in the comfort zone, and Code 0 (fan, baseboard heater, and air conditioner off, internal gains on), the appliances are turned off, Code 0 and the time are filed on disk 2. If room temperature is still within the comfort zone at the next five minute check, this process is repeated for another five minutes, unless the hour is up. For Code 1 (fan precooling) the fan is turned on for 5 minutes, if TR > TA, Code 1 and the time are filed on disk 2, and the duration in RAM is reduced by five minutes. If ambient temperature is too high for pre-cooling, no action is taken until the next five minute readings for TA and TR. for simplicity, the escapes from (10) and (12) to (8) when the requested duration for pre-cool has been met are not shown on the flow chart. For Code 4, (neither pre-heat nor pre-cool required) the fan is turned on or off to move room temperature to within a degree of the middle of the comfort zone.

CHAPTER 5

RESULTS AND DISCUSSION

5.0 Introduction

In order to validate the thermal inertia model of chapter 3, and to obtain the "as built" capacitance and resistors required to use the on line predictive control program, a preliminary experiment was run on Nov, 8, 1984. To obtain the simplest possible thermal inputs for the electric circuit analogy, all of the appliances except the internal gains (a 150 watt light bulb) were disabled. The light bulb was run continuously at constant power for 20 hours to heat the test hut slowly. Nov 8 was chosen retroactively because it was cool enough to keep room temperature within the comfort limits for a time as long as the RC time constant (13 hours) of the test hut, and because the ambient temperature pattern was very close to the pattern predicted from the Fourier series formula (c.f. Fig. 5.1)

Proper operation of the on line predictive control program described in chapter 4 was verified by using it to control all of the test hut appliances for a period of six days beginning on Nov 20, 1984. To obtain some feeling for the savings available with this technique, a calculation using the same electric circuit model, and the same thermal parameters, obtained from the preliminary experiment of Nov 8, but without any pre-cooling, pre-heating, baseboard heating or air conditioner cooling was done for the weather of the same six day period. Whenever the calculated room temperature went above the comfort zone, i.e. over 24 °C (as it happened, calculated room temperatures never went below the comfort zone; c.f. Fig. 5.4), losses through the front panel were calculated for a room temperature of 24 °C. This is close to what would occur if the air conditioner were turned on by a normal thermostat set with its upper dead band limit at 24 °C. Thus, the area above the comfort zone for this calculated room temperature, multiplied by the thermal capacity of the test hut is a rough measure of the purchased cooling prevented by the use of predictive control during those six days.

The measure is only rough because: (a) the model is too simple, even for the test hut; and (b) a cavity controlled to be at a fixed temperature does not reflect what would happen in neighbouring rooms in a real building. With predictive control, the neighbouring rooms would vary in temperature through the comfort zone, pretty well in step with the control room. In our experiment, the measured temperatures are slightly effected by heat gains or losses from or to the cavity whenever the test room temperature is not 20 °C. In other words, the loss resistor, R_{AL} from the test room should either change with temperature, or be calculated with an extra loop containing the cavity temperature. To avoid these complications, R_{AL}, R_{LS}, R_C and C were kept independent of temperature, but were adjusted with a least squares fit to measured test room temperatures over a range of 19 °C to 25 °C. During the six day calculation, the maximum measured temperature difference to ambient cross the front panel was 27 °C, and the minimum was 10 °C. The maximum temperature difference between the cavity and the test room was 4 °C. Since the area between the cavity and the test room is more than 5 times the area of the front panel, this is not a minor effect. However, any savings estimated here would not be entirely valid for a real building in any case. Moreover, six days of data, while enough to show that the on line predictive control system operates as desired, is not enough to extrapolate to an annual savings. Thus, a rough estimate of the savings is sufficient to show that some savings exist, and that they could be large enough to justify refining the program and extending the experiments.

5.1 Preliminary Experiment to Establish "As Built" Thermal Parameters for the Test Hut

For the experiment on Nov. 8, 1984, a modified version of the Time Control program was used to read all 9 temperatures every 15 minutes. None of the appliances were controlled by the program. The internal gain light bulb was switched on manually to provide a constant power heat source. Before the readings shown in Fig. 5.1, the 2 doors to the cavity and test room were left partly open for 3 hours to allow both room temperature and the storage surface temperature to stabilize at 19 °C. Then the doors were closed, and the experiment began at 5 p.m., yielding 20 hourly temperatures for each of the thermometers. The observed room, storage surface and ambient temperatures are shown in Figs 5.1, 5.2, and 5.3.

As derived in Appendix F, the 3 resistors and C were first obtained by inversion of the electric circuit equations, using the measured TA, TR and TS (equations F.9 - F.14) iterated until the solutions were stable. Seventeen different values were obtained for each component, using a set of 4 hourly measurements of TR, TA and TS for each inversion; i.e. one set of C and the 3 resistances was obtained for readings from 17 to 20 hours, another for readings from 18 to 21 hours, etc. The seventeen values so obtained were then averaged to yield:

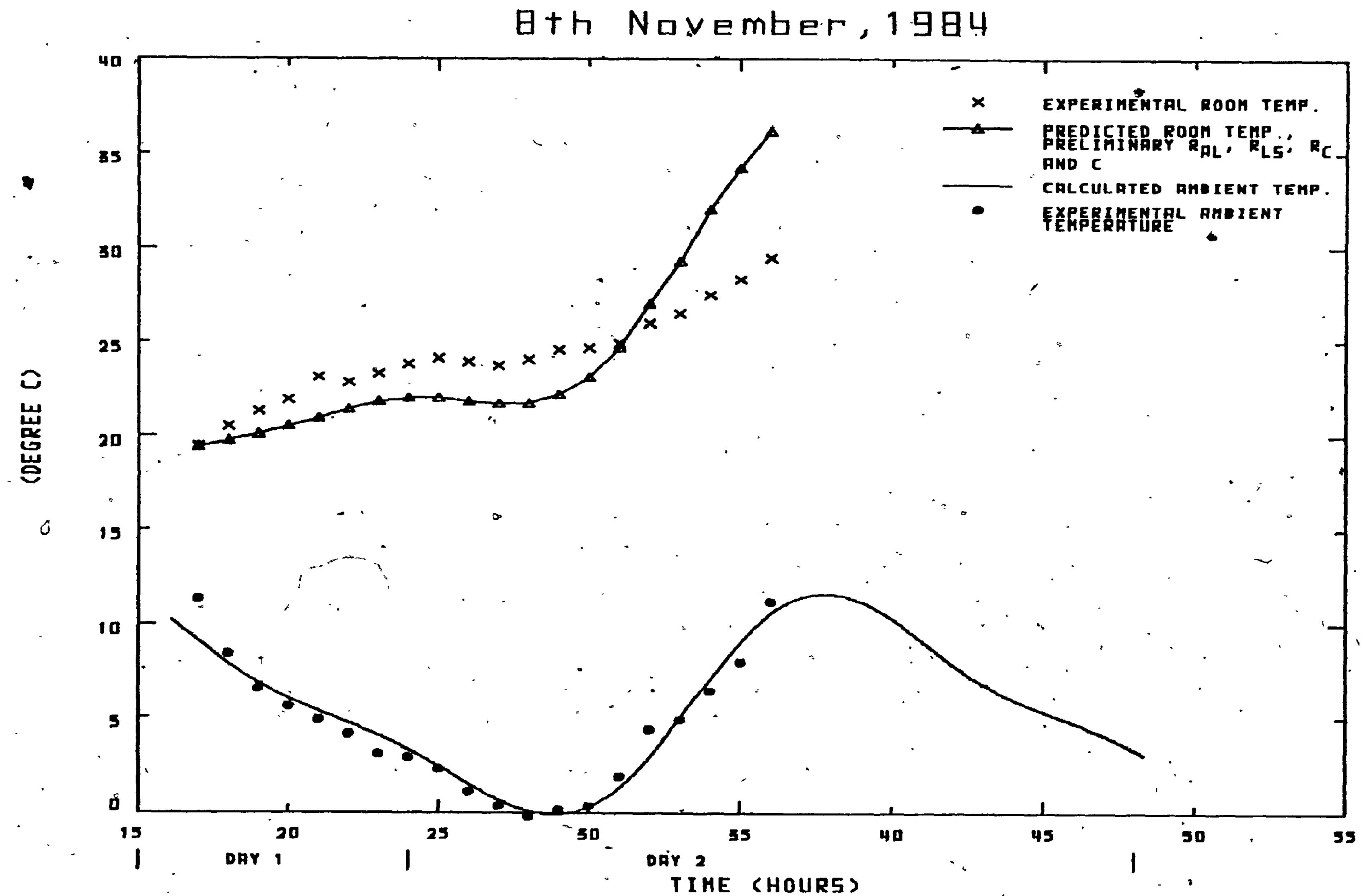


Figure 5.1 Preliminary comparison between measured and predicted room temperatures

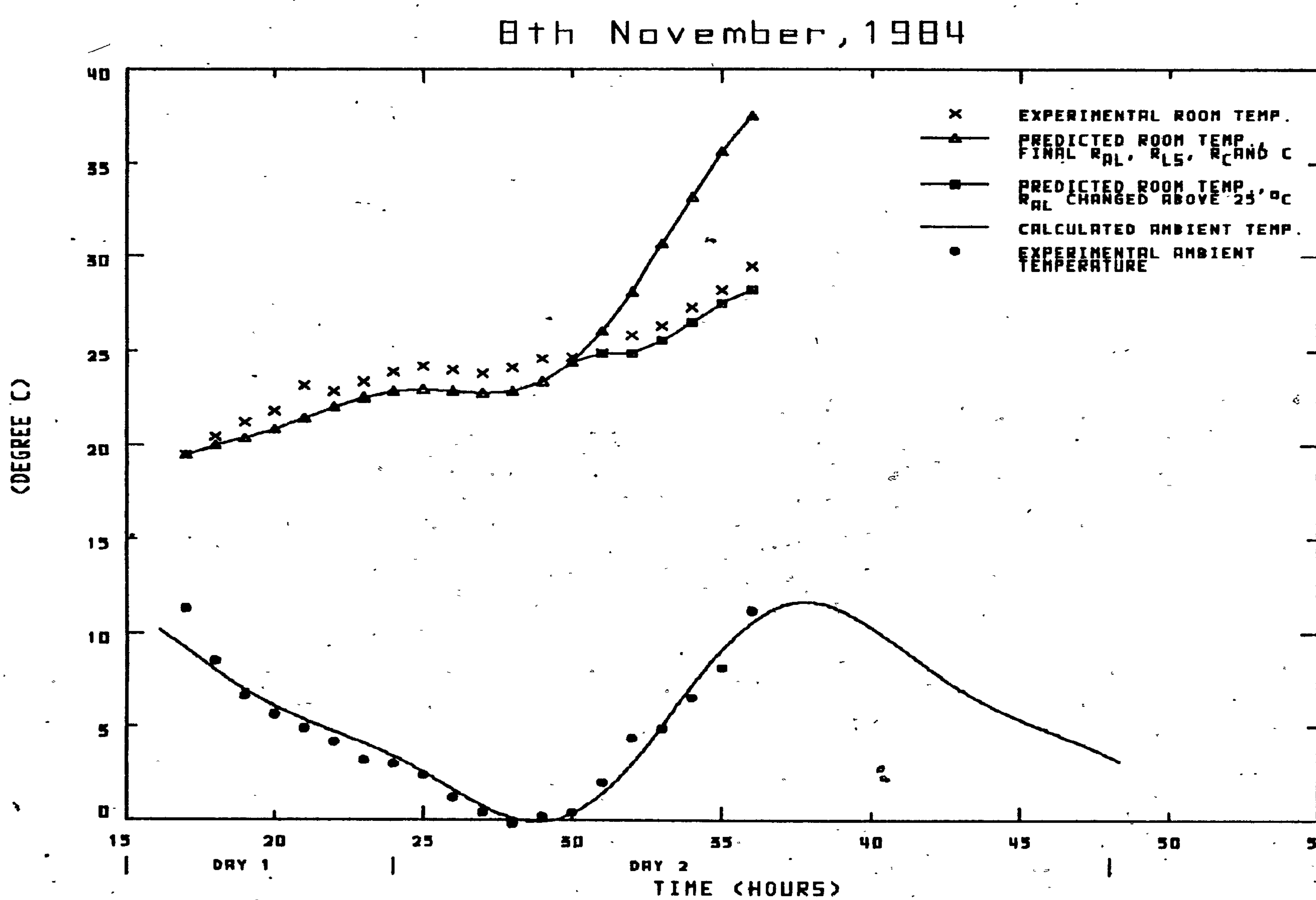


Figure 5.2 Comparison between measured and predicted room temperatures with adjusted R_{AL}, R_{LS}, R_C and C

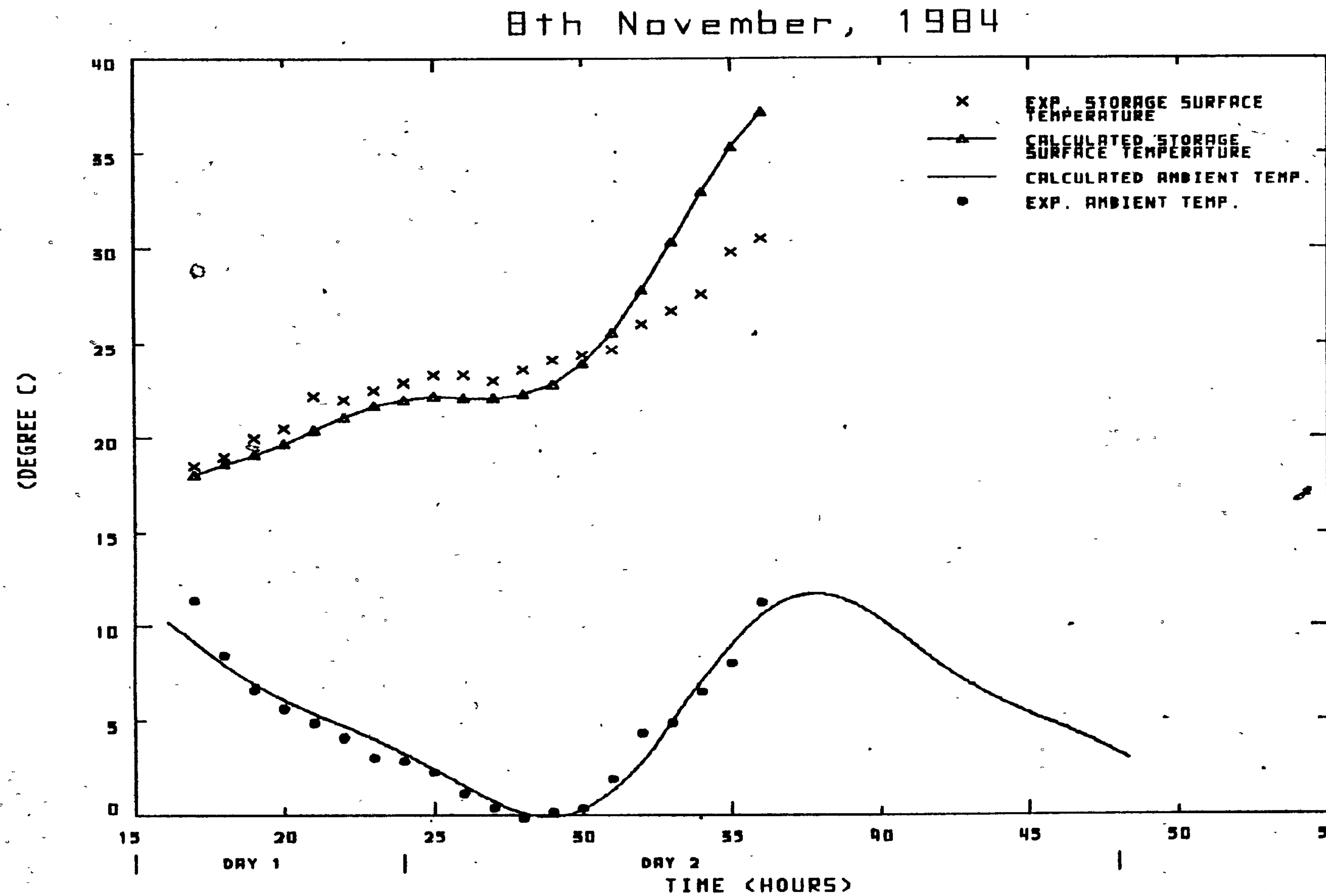


Figure 5.3 Comparison between measured and predicted storage surface temperatures with adjusted R_{AL}, R_{LS}, R_C and C

R_{AL}	=	200	$\pm$ 30	($^{o}C/kW$)
R_{LS}	=	17	$\pm$ 1	($^{o}C/kW$)
R_C	=	12.5	$\pm$ 0.7	($^{o}C/kW$)
C	=	0.059	$\pm$ 0.01	(kW hr/^{o}C)

The errors quoted are standard deviations for each set of 17 values.

With this procedure the averages are influenced less by the first and last few readings than by the others. The first and last readings are only used in one inversion: the second and second last readings are each used in two inversions; while the fourth to sixteenth readings are each used in 4 inversions. This is useful because the time lag between storage and air temperature is not established until a few hours into the experiment, and because the last few room temperatures are well above the cavity temperature (20 ^{o}C), so the simple R_{AL} model used is least appropriate there.

To show the reliability of the circuit model as it is used for on line control, a predicted hourly room temperature was calculated using the above four experimental circuit parameters, plus the Fourier coefficients derived from the smoothed TA for Nov. 8 (i.e. equations F9 - F14). The result is shown in Fig. 5.1.

This kind of iteration procedure is very sensitive to errors in the thermometer readings, as was made clear by a partial sensitivity test. Shifting five of the measured room temperatures by 0.5 °C caused the results for C, R_C, and R_{LS} to change by as much as 100%. Therefore, a least squares fitting procedure was adopted to adjust the above circuit parameters to final values for use in the on line control program.

In the least squares procedure, each of the circuit parameters was changed manually in steps of 1 % or less, above and below the values obtained in the inversion iteration technique. For each change of a single parameter, a new predicted hourly room temperature curve was calculated for Nov. 8. The last 3 points, above 25 °C were excluded from the sum of the squares of the differences between the predicted and measured hourly temperatures. In each case, least square minima were found within 10% of the circuit parameters found by the inversion iteration technique. The order for variation of the circuit parameters was: first R_{AL}; then R_{LS}; then C; and then R_C. R_{AL} is the largest of the parameters, and was not very sensitive to changes in room temperature in the iteration technique, so it was used to minimize the squares of the differences first. The results for this variation gave:

R_{AL}	=	212	($^{o}C/kW$)
R_{LS}	=	15	($^{o}C/kW$)
R_C	=	13	($^{o}C/kW$)
C	=	0.055	($kW\ hr/^{o}C$)

This gives a time constant $\tau = 1/\alpha = C\ (R_{AL}+R_C+R_{LS})$

$$\tau = 13 \text{ hours}$$

The room temperature curve calculated with these adjusted parameters gave a better fit to experiment than that of Fig. 5.1, as shown in Fig. 5.2. Since we are dealing with a four dimensional space, there is some possibility that a lower least squares minimum exists outside of the range searched. The main validation for the circuit parameters obtained is the fact that the on line control worked properly. However, an extra check was obtained by calculating the temperature at the storage surface, with the same circuit and Fourier constants, and comparing it to the measured values, as shown in Fig. 5.3. The maximum difference between predicted and measured temperatures for both Figs. 5.2 and 5.3 is 2 ^{o}C. This is nearly within the experimental difference obtained when all nine thermistors were placed simultaneously in a thermos bottle containing water at about 40 ^{o}C. The maximum and minimum readings differed by 2 ^{o}C. When all 9 thermistors were placed in an accurate electronic ice point device, the difference obtained was only 0.1 ^{o}C.

R_{AL} = 212 ^{o}C/kW corresponds to an R value in British Units of R7.5 (hr.ft^{2}.F/Btu). An A.S.H.R.A.E. [1] calculation using constants for the materials quoted in El Diasty's thesis gave R11. Since the fan and exit damper openings provide extra infiltration and the test hut materials and seals have had four years of deterioration exposed on the roof, and since the effective R value should be reduced by losses to the cavity, R7.5 is a reasonable value.

To check the magnitude of the losses to the cavity when room temperature was above 25 ^{o}C on Nov. 8, a subsidiary calculation was done with R_{AL} reduced by a factor of 4/9 for the last six points of the predicted hourly room temperature curve. The value 4/9 was obtained from A.S.H.R.A.E. calculations for the heat losses through the front panel and the cavity walls at hour 33, with room temperature at 27 ^{o}C, ambient at 5^{o}C, and the cavity at 20 ^{o}C. As shown in Fig. 5.2, the fit is better than the thermometer errors. For on line predictive control in real buildings there is no need to change R_{AL} as a function of room temperature, since the neighbouring rooms will generally be at the same temperatures as the control room. A single R_{AL} was used for this experiment as well, because the appliances were controlled to keep room temperature between 18 ^{o}C and 24 ^{o}C.

5.2 The On Line Predictive Control Experiment

The Data Acquisition and Control systems were operated as outlined in chapter 4, using the thermal parameters as adjusted from the least squares procedure, for a continuous period of 6 3/4 days, beginning at 7 p.m. on Nov. 19, 1984. Thus, the initialization TA file was complete at 7 a.m. Nov. 20, and computer control began then. To create a neutral starting point for the experiment, the test hut doors were partly opened between 11 a.m. and 2 p.m. Nov. 20, until both room temperature and the storage surface temperature stablilized at the middle of the comfort zone, 21 °C. The upper balance temperature for cooling with the air conditioner, BU had been determined in several previous short experiments. BU = -3 °C was used in the control program. Since ambient temperature had never been cold enough during the previous experiments to determine the lower balance point for baseboard heating, BL, an arbitrary value of -10 °C (2 degrees below the lowest ambient previously measured) was used.

Measured results for ambient and room temperature, beginning at 2 p.m. Nov. 20 are shown in Fig. 5.4. The series of F's shown on the figure indicate hours when the fan was on for at least 5 minutes. Neither the baseboard heater nor the air conditioner were used during this period.

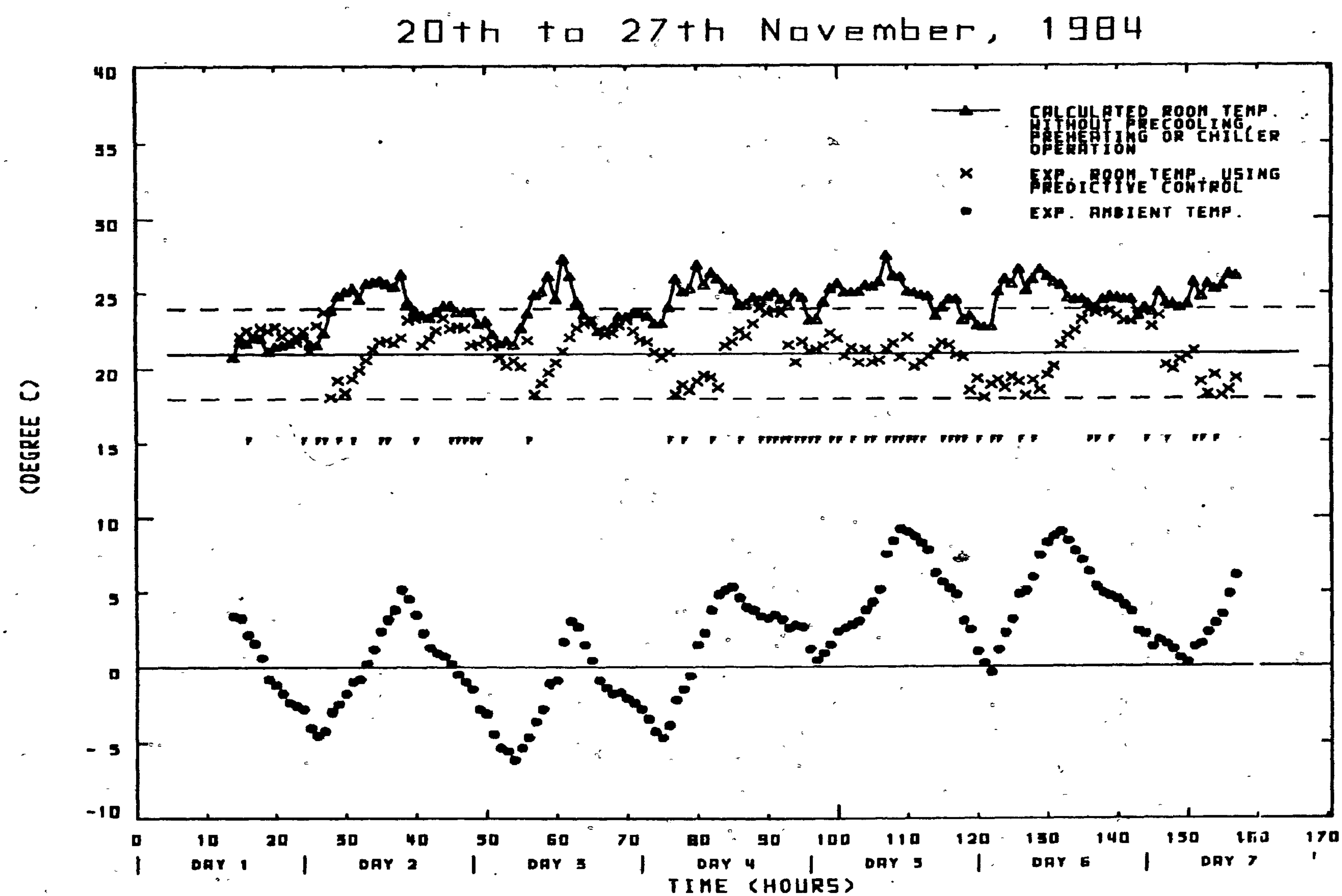


Figure 5.4 Results from on line Predictive Control experiment and calculated curve for estimation of savings.

The ambient curve shows the passage of a warm front near 3 p.m. (hour 87) on day 4. In terms of the prevention of purchased cooling, this is the most inconvenient time for a warm front. The previous strategy selected under normal control had been calculated with the assumption of cooler ambient temperatures than those that actually occured on the afternoon of day 4. The need for a switch to the abnormal control routine cannot be definitely determined until 3 or 4 hours after the beginning of the warm front period. Nevertheless, the pre-cooling obtained in the early morning of day 4, plus the priority given to fan cooling under normal control prevented (just barely) the use of the air conditioner on that afternoon. Room temperature at hour 89 (5 p.m.) just reached 24 °C, but did not exceed it. Soon after the warm front was recognized, at hour 90 or 91, the abnormal control routine operated properly to move room temperature near the middle of the comfort zone, and to keep it within 2 °C of 21 °C for about 15 hours until the return to normal control at hour 105 or 106.

Except during the warm front, precooling was obtained in the early morning each day. Room temperature reached the bottom of the comfort zone several hours before dawn on days 2, 3 and 4, before midnight on day 5, and near dawn on day 7. On day 6, room temperature was kept near the bottom of the comfort zone for a longer period than for days 2, 3 and

4, in anticipation of the higher afternoon ambient temperatures predicted for day 6. Pre-heating was also achieved each evening, except during the warm front, with room temperature reaching the top of the comfort zone after working hours each day except day 5. At noon, room temperature was within 1 ^{o}C of the middle of the comfort zone each day except for day 7, so good comfort was maintained during working hours. During the periods of normal control, all the minima of the room temperature curve were nearly coincident with the minima of the ambient temperature curve, so heat losses at night were reduced compared to what would have occured with control by a regular thermostat without a night setback. Thus, during this six day period, the mass of the test hut was utilized as a thermal storage for "free" heat and cool, even though room temperature never left the comfort zone, good comfort near the centre of the zone was maintained during working hours, no energy was purchased except to run the fan, and night losses were reduced.

The upper curve in Fig. 5.4 shows room temperatures calculated with the same model, ambient temperature and parameter values used in the on line control program, but assuming no fan cooling. Whenever the curve rose above 24 ^{o}C, heat losses through the front panel were calculated as though room temperature were 24 ^{o}C, so the calculated losses are close to those that would have occurred if the air conditioner went on above 24 °C, and off below 24 °C, with no deadband. The internal gains were kept constant at 150 W. for the calculation. No ventilation or cavity losses were assumed beyond those implied in the adjustment of R_{AL} by the least squares fitting procedure. On days 2, 3 and 4, when this curve passes above the comfort zone after a period of at least ten hours below the upper comfort limit, the ambient temperature is about -3 °C, the BU used in the control program. This is an indication that this portion of the software is internally consistent. Little meaning can be derived from the other crossings of the upper comfort limit because they are too close to periods when the curve is above the limit and the calculated room temperature does not match the temperature (24 °C) used for the heat loss calculations. A rough estimate of the cooling energy saved can be obtained by multiplying the area of this curve above the upper comfort limit (105 °C-hr) by the thermal capacity of the test hut (55 W/°C), to give about 6 kWhr of thermal energy savings. With inefficient stop start operation of the air conditioner, this might correspond to a savings of 10 kWhr of electricity. This particular fan uses a power of only 15 watts. It was on for a total of 8.4 hours over the six days, using only 0.1 kWhr, which can be neglected. For a building with 100 offices, and a six day work week, this amounts to a rough savings on cooling of $30 for that week.

However, warmer weeks, with a weekly average ambient temperature near 10 °C would show much larger savings. If we assume an average savings on cooling of $50 per week for 35 weeks, plus equal savings for heating, a rough estimate for the yearly total savings is something over $3000. When the fast morning warmup routine is added to the control program, further large savings will result. For buildings with demand load charges, prevention of chiller or heater operation at peak load times during most billing periods would likely triple the cash savings. The capital cost of such a system produced in reasonable quantities should not exceed $6000.

Three room air temperatures measured in the vertical midplane of the test room are shown for the first four days of the experiment in Fig. 5.5. One thermometer was close to floor level, just behind the front panel, another was at the centre of the room, and the third was close to the ceiling at the back of the room. Evidently, in this temperature range, the relative error between these particular three thermistor thermometers is much less than the absolute difference of 2 °C found for all 9 thermometers at 40 °C. The temperature gradient observed is always in the expected direction, with the back ceiling warmer than the front floor, even though the maximum apparent temperature difference is only 2 °C (hour 41). A small temperature gradient was expect, for two reasons: the cavity had a very

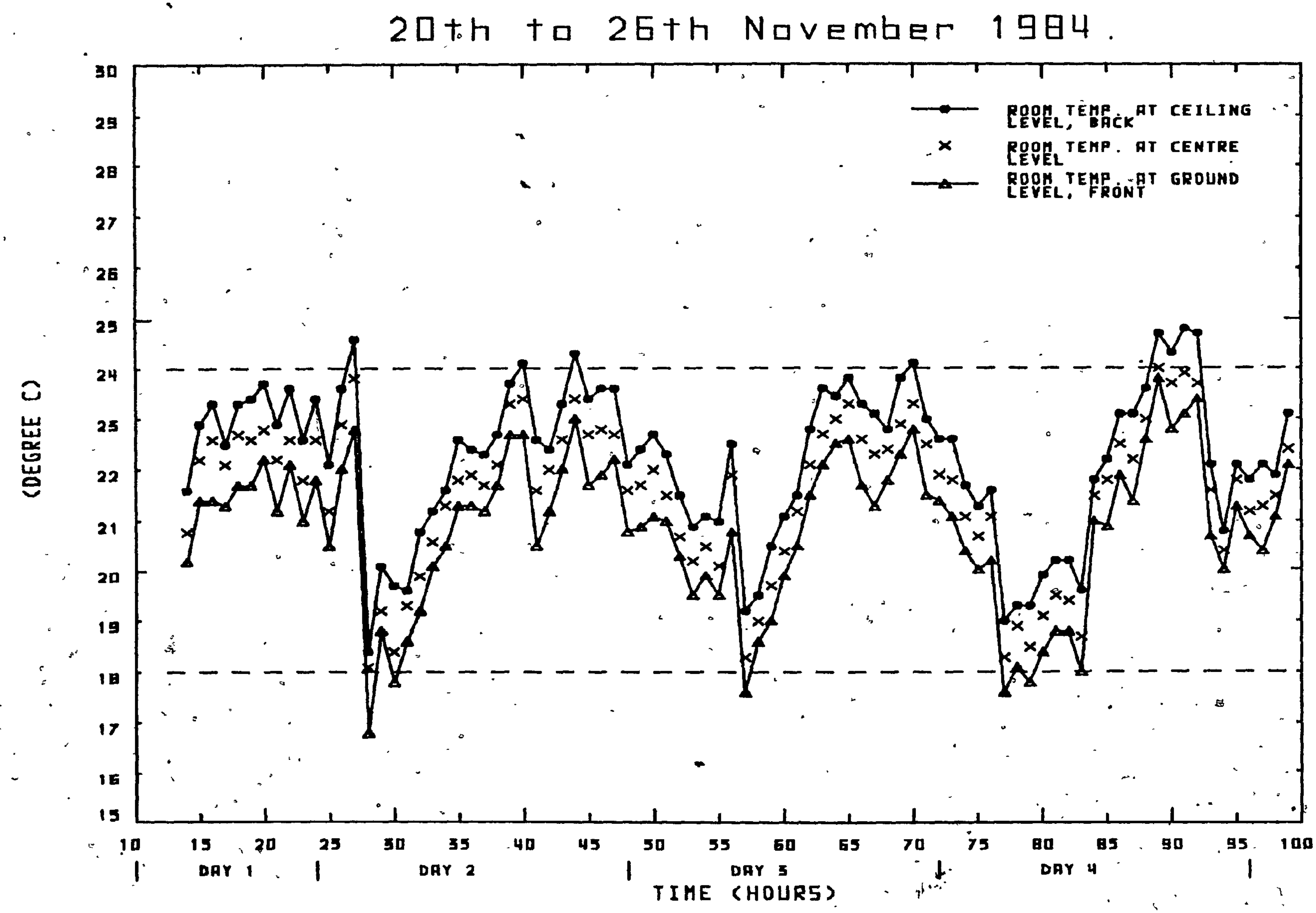


Figure 5.5 Measured air temperatures at three different interior locations

small temperature gradient during heating periods because the heating wires were hung from ceiling to floor at about one foot intervals; also, any heat derived from the concrete block storage was emitted at a low height, since the top of the storage was only 80 cm above the floor.

Whatever the accuracy of the thermometers, these results do show that the average room temperature moves up and down through the horizontal midplane containing the centre thermometer. For instance, at hours 25, 30, 55 and 57 the centre temperature is closer to the front bottom than the back ceiling air temperature. Nearby, at hours 28, 31, and 56 the centre temperature is closer to the ceiling air temperature than the floor air temperature. Thus, the point of adjusting the model thermal parameters is not only to correct for construction errors and changes with settling and weathering, but to find parameters appropriate to a thermometer at a fixed loaction. Such parameters can differ from those appropriate for a heat loss calculation using average room temperature, especially, as would be the case in an occupied room, if the monitoring thermometer is not placed at the centre of the room.

As expected, portions of the room air did go outside the comfort zone at times, even though the centre temperature did not. Eight of the recorded ceiling air temperatures are above 24 °C, and six of the floor air temperatures are below 18 °C. No temperature inversions were recorded, even though the fan cooling was applied near the ceiling level.

5.3 Conclusions

1. The ambient temperature prediction system developed here, using a short Fourier series, with 3 constants derived from weather records and one from recent on site temperature measurements read into an Apple microcomputer, predicts normal ambient temperatures 24 hours in advance closely enough for use in building control systems. The Apple program developed is fast enough for use in on line H.V.A.C. control systems. This system can be used to sense the arrival or departure of a weather front within 3 or 4 hours of the event, allowing microcomputer controlled changes of H.V.A.C. control strategy in time to prevent energy waste, for most weather fronts.

2. The room temperature prediction system developed here, using closed solutions for the simple one capacitor model of the thermal flows, plus the predicted ambient temperatures, one measured room temperature, and appropriate "as built" thermal parameters for the test hut, predicts the centre temperature of the test room air closely enough for use in the test hut H.V.A.C.

control system. It is likely, but not yet proven, that this system will also work well enough in more complex buildings.

3. The preliminary Apple microcomputer based Predictive Control system developed here worked well in a short 6 day trial with the simple 3 element H.V.A.C. system of the test hut. More software must be developed before the system can be used in an occupied building, and longer trials must be done, but the essential elements of the system are in place. Low cost hardware has been used to monitor the temperatures required and to switch the H.V.A.C. subsystems on and off. Apple software has been developed to predict both ambient and room temperature 24 hours in advance, to change control strategies when unusual weather occurs, to calculate the optimal amount of pre-heating or pre-cooling required 24 hours in advance, with revisions each hour as indoor or outdoor conditions change, and to take action to obtain the calculated amounts of internal gain heating or fan cooling. During the six day trial, enough savings through prevention of use of the air conditioner were obtained to allow the hope that the fully developed system will be cost effective.

4. More development of the system is warranted.

5.4 Recommendations for Further Studies

1. More on line control experiments should be done, at all seasons of the year, with the present program and test hut configuration. This will provide estimates for the energy savings expected during each season, and for how often the passage of a weather front induces operation of the air conditioner or baseboard heater with the present software.

2. More complex strategies for the abnormal weather routine should be tested and compared with the present one. For example, one might move room temperature to the bottom of the comfort zone for warm fronts occuring after midnight, or for warm fronts with recorded temperatures well above those that had been predicted for normal weather.

3. More experiments should be done to check the present ambient temperature prediction and weather front recognition system at different seasons of the year. This will provide estimates for the worst case longest time before recognition of a weather front with the present software, and for the worst error expected in the ambient temperature prediction for normal weather.

4. A computerized method for evaluating "as built" thermal parameters for the electric circuit model should be

developed and validated. This will allow automatic seasonal variation of these parameters with the on line control program.

5. The room temperature prediction system should be validation for more complex buildings than the test hut. This will help clarify the limitations of the simple one capacitor model used for the thermal flows.

6. To move towards using this system for predictive control in occupied buildings, several software routines should be added to the system, and validated by experiments:
   (a) Minimum ventilation air should be maintained during occupied hours. This involves either proportional control of the fan or control of a multiple fan system, plus control of the mixing and outside air dampers, for large buildings.
   (b) Night temperature set backs or set ups outside the comfort zone should be added. This could be combined with a routine for moving the comfort zone seasonally. The extra set back or set up should only be used when pre-cooling or pre-heating within the comfort zone is not enough to prevent the predicted use of purchased energy the next day. (i.e. it would not be used often)
   (c) A fast morning warm up or cool down of room air

temperature to the centre of the comfort zone should be added. This will involve a comparison both of energy usage and of comfort attained in the two cases of fast or normal warm up.

(d) For summer use, calculation of dehumidification strategies should be added. This will involve the addition of ambient and indoor humidity sensors. Extra savings will sometimes be available from ventilation beyond that required for pre-cooling, to keep the moisture content of the indoor building materials as low as possible.

(e) A prediction of maximum and minimum solar gains 24 hours in advance should be added. On many days, a single pre-heating or pre-cooling strategy will cover both cases, with predicted room temperatures never outside the comfort zone for either extreme of solar gains. On the other days, however, what amounts to a prediction of solar gains will have to be made. One possibility is simply to use the historical average solar gains. Another is to install a solarimeter to monitor, say sunlight on a horizontal plane, and extract probabilities for strings of sunny and cloudy days in a row for each week from the weather records. In November in Montreal, one can predict with good certainty that after 3 sunny days in a row, the fourth day will be cloudy.

(f) The on line program should be extended to handle buildings with several zones, each with a different set of internal gains, thermal loss and inertia parameters, and controls for the H.V.A.C. system.

7. A research program should be initiated to test whether methods to predict the arrival of weather fronts in advance, using only on site measurements and historical weather records, are possible. Small ambient pressure and temperature variations, or changes in the pattern of wind variations during normal weather might provide advance clues. Most probable intervals between weather fronts for the various seasons could be extracted from the weather records. With such predictions, action could be taken during normal weather periods to prevent the use of purchased energy during passage of the next weather front.

REFERENCES

1. ASHRAE Handbook of Fundamental, New York, 1981.

2. Beyer, W.H., "CRC Standard Mathematical Tables", Published by CRC Press, April 1978.

3. Burden, R.L., Faires, J.D., Reynolds, A.C., "Numerical Analysis", Published by Prinale Weber & Schmidt, Boston August, 1980.

4. C.C.S., "Apple II 3-3/4 Digit BCD A/D Converter Owner's Manual", published by California Computer System, 1979.

5. Cudbird, B.S.V., "Diurnal Average of Wind, Atmospheric Pressure and Temperature at Selected Canadian Stations", Dept. of Transport, Meteorological Branch, CIR-4114, CLI-33. Sept 22, 1964, 43p.

6. El-Diasty, R., "An Investigation of Window Systems for Reduced Energy Consumption", Ph.D. Thesis, Centre for Building Studies, Concordia University, Canada, August, 1982.

7. Espinosa, C., "Apple II Reference Manual", published by Apple Computer Inc., 1979.

8. Garrison, P., Montreal Branch of Environment Canada, Personal Commumication, in April 1984.

9. Goldstein, D.B., Lokmanhekim, M., Clear, R.D., " A simple Method for Computing the Dynamic Response of Passive Solar Buildings to Design Weather Conditions", Lawrence Berkeley Laboratory Report LBL-9787 (1979); Presented at the Miami International Conference on Alternative Energy Sources, Miami Beach, Fl, USA, 10 Dec. 1979.

10. Goldstein, D.B., Lokmanhekim, M., Clear, R.D.,"Design Calculation for Passive Solar Building using a Programmable Caculator", Lawrence Berkeley Laboratory Report LBL-9371 (1979); Presented at the Izmir Internation Symposium-II on Solar Energy Fudamentals and Application, Izmir, Turkey, 6-8 August, 1979.

11. Hartman, T., "Dynamic Control of Heat Called Key to Saving Energy", Air-conditioning, Heating and Refrigeration News, Sept. 1, 1980.

12. Hitkari, J., "Prediction Algorithms for Small Computer Implementation", M. Sc. Thesis, Concordia University, Montreal, Canada, June 1981.

13. Kerr, R., Shapiro, M., and Turaga, M., " A Performance Evaluation of a Partially Solar Heated House in Quebec", Solar Energy Update, 77, SESCI (Edmonton 1977).

14. Kerr, R.G., Shapiro, M.M., Turaga, M., and McConnell R.,

"A Performance Evaluation of a Partly Solar Heated House in Quebec", Proceedings of the 1977 Annual Meeting American Section of ISES, Vol. 1, SEction 13-1 (Orlando, 1977).

15. Kerr, R.G., "A Study of a Solar Heated House in Quebec", M. Eng. Thesis, Centre for Building Studies, Concordia University, Montreal, Canada, March 1978.

16. Kreith, J.F., Kreider, J.F., "Principles of Solar Engineering", Washington, D.C., Hemisphere Publishing Corporation, McGraw Hill Book Company, 1978.

17. Kreider, J.F., Kreith, F., "Solar Energy Handbook", McGraw Hill Book Company, 1981., Ch. 2.

18. Olesen, B.W., "Thermal Comfort", Technical Review No. 2, Published by Bruel & Kjaer, 1982.

19. Powe, N.N., et. al., "The Climate of Montreal", Environment Canada, Climatological Studies number 15, 1969.

20. Rollefson, J.P., "NRC's Solar Energy Program Identifies Passive Research and Development as Highest Priority", Published by Solar Energy Society of Canada, SOL, March 1984.

21. Shapiro M.M., "Passive Solar Buildings: Effective Design

Techniques", Notes for Short Courses held on May 15-16, 1980, Centre for Building Studies, Concordia University, Ch. 4 & Ch. 8.

22. Shapiro, M.M., Connolly, R.E., "Thermal Performance of a Commercial Solar Greenhouse in Montreal", Proceedings of SESCI-Montreal 81, pp. 48-53, Annual Conferenceof SESCI August 1981.

23. Yager, A., "A Study of the La Macaza Solar Heated House", M. Eng. Thesis, Centre for Building Studies, Concordia University, Canada, March, 1980.

APPENDIX A

```
      PROGRAM MAIN
C                                                              C
C        This is a curve fitting program, with adoption of     C
C     least square method, to generate a Fourier series        C
C     curve.                                                   C
C                                                              C
C     Symbol :                                                 C
C         X   =  X values of data points.                      C
C         Y   =  Y values of data points.                      C
C         F   =  Function matrix.                              C
C        FT   =  Tranpose of fuction matrix.                   C
C         A   =  Product of matrix FT and F.                   C
C         B   =  Product of matrix FT and Y.                   C
C         C   =  Coefficient of Fourier Series.                C
C        YY   =  Values of Y at X by the curve.                C
C        OM   =  Frequency (2*PI/24)                           C
C     THETA   =  Phase angle.                                  C
C         N   =  Number of point.                              C
C         M   =  Number of degree.                             C
C       CHE   =  Title of curve.                               C
C                                                              C
      DIMENSION X(50),Y(50),F(50,7),FT(7,50),A(7,8),B(7),C(7),
     $          YY(50)
      COMMON C,OM
      CHARACTER*25 CHE
      CHARACTER*1 TEM
      OM=2*3.1415927/24
C                                                              C
C        Read in the title of the curve.                       C
C                                                              C
    1 READ (5,'(C25)') CHE
      WRITE (6,100) CHE
C                                                              C
C        Read in the number of constants C and number of data  C
C     points.                                                  C
C                                                              C
      READ(5,*) M,N
C                                                              C
C        Read X-Y values of data points and generate a F       C
C     matrix.                                                  C
C                                                              C
      DO 2 I = 1,N
      READ (5,*) X(I),Y(I)
      F(I,1)=1.
      F(I,2)=COS(OM*X(I))
      F(I,3)=SIN(OM*X(I))
      F(I,4)=COS(2*OM*X(I))
      F(I,5)=SIN(2*OM*X(I))
    2 CONTINUE
C                                                              C
C        Generate the transpose of the F matrix.               C
C                                                              C
      DO 3 I=1,N
      DO 3 J=1,M
      FT(J,I)=F(I,J)
    3 CONTINUE
C                                                              C
```

```
C         Determine the coefficients of a simultaneous              C
C       equation system, matrix A.                                  C
C                                                                   C
        CALL MATMPY(FT,F,A,M,N,M)
C                                                                   C
C         Determine the column of constants of the simultaneous     C
C       equation system.                                            C
C                                                                   C
        CALL MATMPY(FT,Y,B,M,N,1)
        DO 4 I=1,M
      4 A(I,M+1)=B(I)
C                                                                   C
C         Determine C values by solving simultaneous equation       C
C       using Cholesky Method.                                      C
C                                                                   C
        MP1=M+1
        CALL CHLSKY(A,M,MP1,C)
C                                                                   C
C         Determine the phase angle.                                C
C                                                                   C
        THETA=(ATAN(C(2)/C(3))+3.1415927)/3
C                                                                   C
C         Curvefit the data again using only one phase angle and    C
C       1 overtune Fourier series.                                  C
C                                                                   C
        M=M-2
C                                                                   C
C         Generate the F matrix.                                    C
C                                                                   C
        DO 5 I=1,N
        F(I,1)=1.
        F(I,2)=SIN(OM*X(I)+3*THETA)
        F(I,3)=SIN(2*OM*X(I)+THETA)
      5 CONTINUE
C                                                                   C
C         Generate the transpose of the F matrix.                   C
C                                                                   C
        DO 6 I=1,N
        DO 6 J=1,M
        FT(J,I)=F(I,J)
      6 CONTINUE
C                                                                   C
C         Determine the coefficients of matrix A.                   C
C                                                                   C
        CALL MATMPY(FT,F,A,M,N,M)
C                                                                   C
C         Determine the column of constants of the simultaneous     C
C       equation system.                                            C
C                                                                   C
        CALL MATMPY(FT,Y,B,M,N,1)
        DO 7 I=1,M
      7 A(I,M+1)=B(I)
C                                                                   C
C         Determine C values by solving simultaneous equation       C
C       using Cholesky Method.                                      C
C                                                                   C
        MP1=M+1
```

```
      CALL CHLSKY(A,M,MP1,C)
C                                                                   C
C       Calculate the value of Y at point X of the curve.           C
C                                                                   C
      DO 8 I=1,N
    8 YY(I)=C(1)+C(2)*SIN(OM*X(I)+3*THETA)+C(3)*SIN(2*OM*X(I)+
     $        THETA)
      WRITE(6,200) THETA
      WRITE(6,300) (I,C(I),I=1,M)
      WRITE(6,400)
C                                                                   C
C       Calculate the absolute different and print the data.        C
C                                                                   C
      DO 9 I=1,N
      DF=ABS(Y(I)-YY(I))
    9 WRITE(6,500) X(I),Y(I),YY(I),DF
C                                                                   C
C       Check whether there is another set of data.                 C
C                                                                   C
      READ(5,'(C1)') TEM
      IF (TEM .EQ. 'Y') GOTO 1
  100 FORMAT(1H1,T10,'TEMPERATURE VARIATION CURVE FITTING FOR ',
     $         C25,///,T10,'POWER REGRESSION:- ',/,
     $         /,T15,'Y = C(1)+C(2)',
     $         'SIN(OM*X+3*THETA)+C(3)*SIN(2*OM*X+THETA)',//,
     $         T44,'WHERE OM     = 2*PI/24')
  200 FORMAT(' ',T50,'THETA = ',F8.6,//,
     $         29X,'C(1) THROUGH C(M)'/)
  300 FORMAT(1H ,26X,'C(',I1,') = ',E14.7)
  400 FORMAT(1H ,//,T12,'ACTUAL',T27,'ACTUAL',T41,'CALCULATED',
     $         T56,' ABSOLUTE ',/,
     $         T15,'X',T30,'Y',T45,'Y',T56,'DIFFERENCE')
  500 FORMAT(7X,3(2X,F8.2,5X),5X,F6.2)
      STOP
      END
```

NO ERRORS:F7D R04-00   MAINPROG   MAIN   TABLE SPACE: 4 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES   STACK SPACE: 178 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTRAN-VIID R04-0 20/02/85 10:04:40 PAGE 1/ 4


```
      SUBROUTINE MATMPY(A,B,C,M,N,L)
C                                                               C
C       Subroutine to perform matrix multiplication.            C
C                                                               C
      DIMENSION A(7,50),B(50,7),C(7,8)
C                                                               C
C       Determine matrix C as product of A and B matrix.        C
C                                                               C
      DO 1 I=1,M
      DO 1 J=1,L
      C(I,J)=0
      DO 1 K=1,N
    1 C(I,J)=C(I,J)+A(I,K)*B(K,J)
      RETURN
      END
```

```
NO  ERRORS:F7D  R04-00    SUBROUTINE  MATMPY    TABLE SPACE:   1 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 172 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
FORTRAN-VIID R04-0                         20/02/85  10:04:40  PAGE   1/      5

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002
      SUBROUTINE CHLSKY(A,N,M,X) **
C                                                                        C
C       Subroutine using Cholesky's method to generate                   C
C     solutions for the simultaneous linear algebraic equation           C
C                                                                        C
      DIMENSION A(7,8),X(7)
C                                                                        C
C       Calculate first row of upper unit triangular matrix.             C
C                                                                        C
      DO 1 J=2,M
    1 A(1,J)=A(1,J)/A(1,1)
C                                                                        C
C       Calculate other elements of Upper and Lower matrices.            C
C                                                                        C
      DO 6 I=2,N
      J=I
      DO 3 II=J,N
      SUM =0.
      JM1=J-1
      DO 2 K=1,JM1
    2 SUM=SUM+A(II,K)*A(K,J)
    3 A(II,J)=A(II,J)-SUM
      IP1=I+1
      DO 5 JJ=IP1,M
      SUM=0.
      IM1=I-1
      DO 4 K=1,IM1
    4 SUM=SUM+A(I,K)*A(K,JJ)
    5 A(I,JJ)=(A(I,JJ)-SUM)/A(I,I)
    6 CONTINUE
C                                                                        C
C       Solve for X(I) by back substitution.                             C
C                                                                        C
      X(N)=A(N,N+1)
      L=N-1
      DO 8 NN=1,L
      SUM=0.
      I=N-NN
      IP1=I+1
      DO 7 J=IP1,N
    7 SUM=SUM+A(I,J)*X(J)
    8 X(I)=A(I,M)-SUM
      RETURN
      END

NO  ERRORS:F7D  R04-00     SUBROUTINE  CHLSKY     TABLE SPACE:    2 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE:  177 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

** James, M.L., et. al., "Applied Numerical Methods for Digital Computation", University of Nebraska, Dun Donnelley Publisher, New York, Second Ed., p193-199.

APPENDIX B

BASIC 05/01 13:07:34

APPLESOFT BASIC PAGE 1

```
0010 REM
0020 REM     THIS IS A DATA ACQUISITION PROGRAM WHICH IS USED
0030 REM   FOR DATA COLLECTION OF AN INTERVAL OF TIME. THIS
0040 REM   DATA WILL STORE IN DISK B.
0050 REM
0060 REM
0070 REM                   RWTS SUBROUTINE
0080 REM     TO ACESS DISK WITHOUT THE USE OF DISK OPERATING SYSTEM
0090 REM   (DOS).
0100 REM
0110       FOR X = 896 TO 927
0120       READ P
0130       POKE X,P
0140       NEXT
0150       DATA 169,3,160,138,32,217,3,96,0,0,1,96,2,0,0,0,155,3,0,96,0,0,2,
            0,0,96,1,0,1,239,216,118
0160       DIM AD(12),TT$(10,40)
0170 REM
0180 REM   SYMBOLS
0190 REM     AD  =  NUMBER OF DAY OF EACH MONTH.
0200 REM     TT  =  TEMPORARY STORAGE OF DATA BEFORE ACCESS TO DISK.
0210 REM     ST  =  SECTOR NUMBER
0220 REM     TR  =  TRACK NUMBER.
0230 REM     IN  =  NUMBER OF TRACK PER CHANNEL.
0240 REM     SC  =  TIME INTERVAL BETWEEN EACH READING IN SECOND.
0250 REM
0260 REM
0270 REM     INITIAL VARIABLES
0280 REM
0290       D$ =  CHR$ (4)
0300       LL = 1
0310       LD = 0
0320       ST = 0
0330       FOR I = 1 TO 12
0340       READ AD(I)
0350       NEXT
0360       DATA  31,28,31,30,31,30,31,31,30,31,30,31
0370       HOME : VTAB (10)
0380       INPUT "  INPUT NUMBER OF CHANNEL(S)                ";NC
0390       INPUT "  TIME INTERVAL BETWEEN EACH READING (SEC) ";SC
0400       IN =  INT (35 / NC)
0410 REM
0420 REM     STORE NUMBER OF CHANNELS AND READING'S INTERVAL BETWEEN
0430 REM   EACH CHANNEL IN MEMORY. CALL SUBROUTINE TO STORE THIS
0440 REM   INFORMATION, AS WELL AS TITLE, UNIT, AND FACTOR IN LAST
0450 REM   TRACK OF THE DISK B.
0460 REM
0470       POKE 24576,NC
0480       TP =  INT (SC / 10000)
0490       POKE 24584,TP
0500       TP =  INT ((SC - TP * 10000) / 100)
0510       POKE 24585,TP
0520       TP =  INT (SC -  INT (SC / 100) * 100)
0530       POKE 24586,TP
0540       GOSUB 2130
0550       TR = 0
0560       ST = 0
0570 REM
0580 REM     LOAD ASSEMBLY LANGUAGE AA/DD IN MEMORY. THIS
0590 REM   PROGRAM ACCEPT AND TERMINATE ONLY ONE SET OF DATA
0600 REM   IN MEMORY AT A TIME.
```

```
0610 REM
0620      PRINT D$;"BLOAD AA/DD"
0630 REM
0640 REM     RESET TO FIRST CHANNEL.
0650 REM
0660      HOME
0670      POKE 49245,1
0680      GOSUB 2050
0690      POKE 49244,0
0700 REM
0710 REM     GET THE INITIAL TIME OF THE FIRST READING.
0720 REM
0730      GOSUB 1440
0740      GOTO 1030
0750      PRINT D$;"IN#4"
0760      PRINT D$;"PR#4"
0770      INPUT " ";T1$
0780      PRINT D$;"IN#0"
0790      PRINT D$;"PR#0"
0800 REM
0810 REM      CONVERT THE TIME INTO NUMERCIAL NUMBER AND PRINT
0820 REM   THE TIME IN SCREEN.
0830 REM
0840      M1 =  VAL ( MID$ (T1$,1,2))
0850      D1 =  VAL ( MID$ (T1$,4,2))
0860      H1 =  VAL ( MID$ (T1$,7,2))
0870      M2 =  VAL ( MID$ (T1$,10,2))
0880      S1 =  VAL ( MID$ (T1$,13,2))
0890      VTAB (8): HTAB (15)
0900      PRINT  LEFT$ (T1$,14)
0910 REM
0920 REM   CHECK WHETHER THE RIGHT TIME FOR ANOTHER READINGS.
0930 REM
0940      IF (M1 < MT) GOTO 750
0950      IF (D1 < D) GOTO 750
0960      IF (H1 < H) GOTO 750
0970      IF (M2 < M) GOTO 750
0980      IF (S1 < S) GOTO 750
0990 REM
1000 REM     TRANSFER SENSOR'S DATA TO MEMORY AND PRINT
1010 REM   THE DATA IN SCREEN.
1020 REM
1030      VTAB (10 + LL): HTAB (16)
1040      PRINT LL;" ";
1050      TP$ = ""
1060      FOR X = 0 TO 5
1070      SE =  PEEK (49856 + X)
1080      TP$ = TP$ +  CHR$ (SE)
1090      NEXT
1100      PRINT TP$
1110      TT$(LL,LD) = TP$
1120      LL = LL + 1
1130 REM
1140 REM     CHECK WHETHER ALL CHANNELS HAVE BEEN PROCESSED.
1150 REM   IF NOT, ADVANCE ONE CHANNEL TO CONVERT DATA AGAIN.
1160 REM   IF ALL CHANNELS ARE PROCESSED RESET THE SENSORS
1170 REM   BACK TO FIRST CHANNEL.
1180 REM
1190      IF (LL > NC) GOTO 1270
1200      POKE 49241,1
1210      GOSUB 2050
```

```
1220      POKE 49240,0
1230      FOR I = 1 TO 400
1240      CALL 49664
1250      NEXT
1260      GOTO 1030
1270      LL = 1
1280      POKE 49245,1
1290      GOSUB 2050
1300      POKE 49244,0
1310      LD = LD + 1
1320 REM
1330 REM      CHECK WHETHER ALL THE MEMORY IS OCCUPIED. IF YES
1340 REM     GOTO SUBPROGRAM STORAGE
1350 REM
1360      IF (LD > 39) THEN  GOTO 1710
1370      T$ = T1$
1380      GOSUB 1510
1390      GOTO 750
1400 REM
1410 REM      GET THE TIME FROM THE CLOCK AND CONVERT THE TIME INTO
1420 REM    NUMERCIAL VALUE AND CALCULATE THE NEXT READING TIME.
1430 REM
1440      PRINT D$;"IN#4"
1450      PRINT D$;"PR#4"
1460      INPUT " ";T$
1470      PRINT D$;"IN#0":
1480      PRINT D$;"PR#0"
1490      T2$ = T$
1500      T1$ = T$
1510      MT =  VAL ( MID$ (T$,1,2))
1520      D =  VAL ( MID$ (T$,4,2))
1530      H =  VAL ( MID$ (T$,7,2))
1540      M =  VAL ( MID$ (T$,10,2))
1550      S =  VAL ( MID$ (T$,13,2))
1560      S = S + SC
1570      M = M +  INT (S / 60)
1580      S = S -  INT (S / 60) * 60
1590      H = H +  INT (M / 60)
1600      M = M -  INT (M / 60) * 60
1610      D = D +  INT (H / 24)
1620      H = H -  INT (H / 24) * 24
1630      MT = MT +  INT (D / AD(MT))
1640      D = D -  INT (D / AD(MT)) * AD(MT)
1650      IF (MT > 12) THEN MT = MT - 12
1660      RETURN
1670 REM
1680 REM          SUBPROGARM STORAGE
1690 REM      THIS SUBPROGRAM STORE READINGS IN DISK B.
1700 REM
1710      POKE 911,ST
1720      FOR II = 1 TO 14
1730      TP =  ASC ( MID$ (T2$,II,1))
1740      POKE (24575 + II),TP
1750      NEXT
1760      FOR KK = 1 TO NC
1770      POKE 910,(KK - 1) * IN + TR
1780      FOR JJ = 0 TO 39
1790      FOR II = 1 TO 6
1800      TP =  ASC ( MID$ (TT$(KK,JJ),II,1))
1810      POKE (24591 + JJ * 6 + II),TP
1820      NEXT II
```

```
1830       NEXT JJ
1840       CALL 896
1850       NEXT KK
1860 REM
1870 REM       GET THE TIME FROM CLOCK AND CHECK WHETHER THE DISK
1880 REM    IS FULL. IF YES, THE PROGRAM IS COMPLETED.
1890 REM
1900       PRINT D$;"IN#4"
1910       PRINT D$;"PR#4"
1920       INPUT " ";T1$
1930       PRINT D$"IN#0"
1940       PRINT D$;"PR#0"
1950       T2$ = T1$
1960       LD = 0
1970       ST = ST + 1
1980       IF (ST > 16) GOTO 1030
1990       ST = 0
2000       TR = TR + 1
2010       IF (TR  > = IN) END
2020 REM
2030 REM       DELAY SUBROUTINE
2040 REM
2050       FOR I = 1 TO 300
2060       NEXT
2070       RETURN
2080 REM
2090 REM       READ IN CHANNEL TITLE, UNIT AND THE MULTIPLICATION
2100 REM    FACTOR OF EACH CHANNEL. STORE THESE DAT IN THE LAST TRACK
2110 REM    OF THE DISK.
2120 REM
2130       I = 1
2140       FOR II = 1 TO NC
2150       PRINT "  INPUT TITLE OF CHANNEL ";II
2160       INPUT TP$
2170       FOR J = 1 TO 32
2180       IF ( MID$ (TP$,J,1) = "") THEN TP = 0: GOTO 2200
2190       TP =  ASC ( MID$ (TP$,J,1))
2200       POKE (24591 + (I - 1) * 64 + J),TP
2210       NEXT
2220       PRINT "  INPUT THE UNIT OF THIS CHANNEL"
2230       INPUT TP$
2240       FOR J = 1 TO 16
2250       IF ( MID$ (TP$,J,1) = "") THEN TP = 0: GOTO 2270
2260       TP =  ASC ( MID$ (TP$,J,1))
2270       POKE (24623 + (I - 1) * 64 + J),TP
2280       NEXT
2290       PRINT "  INPUT THE FACTOR OF THIS CHANNEL"
2300       INPUT FA
2310       TP =  INT (FA / 100)
2320       FA = FA - TP * 100
2330       POKE (24639 + (I - 1) * 64 + 1),TP
2340       POKE (24639 + (I - 1) * 64 + 2),FA
2350       IF (II = NC) THEN  GOTO 2370
2360       IF ( INT (II / 3) * 3  < > II) THEN I = I + 1: GOTO 2430
2370       POKE 910,34
2380       POKE 911,ST
2390       ST = ST + 1
2400       CALL 896
2410       POKE 911,ST
2420       I = 1
2430       NEXT
```

```
2440    RETURN
```

```
0010 REM   +
0020 REM     THIS PROGRAM IS FOR RETRIEVEING DATA FROM DISK B,
0030 REM   STORED BY DATA ACQUISITION PROGRAM.
0040 REM
0050       DIM B(10,40),B$(10),C(10),C$(10),AD(12),D(10)
0060 REM
0070 REM   SYMBOLS
0080 REM     B  =  DATA FROM MEMORY OF ONE TRACK
0090 REM     B$ =  TITLE NAME OF CHANNELS
0100 REM     C$ =  UNIT OF CHANNEL
0110 REM     C  =  MULTIPLICATION FACTORS
0120 REM     AD =  NUMBER OF DAY OF EACH MONTH
0130 REM     D  =  ARRAY TO STORE MONTH, DAY, HOUR, MINUTE AND SECONG
0140 REM     ST =  SECTOR NUMBER
0150 REM     TR  =  TRACK NUMBER
0160 REM     IN  =  NUMBER OF TRACK PER CHANNEL
0170 REM     SC  =  TIME INTERVAL BETWEEN EACH READING IN SECOND.
0180 REM
0190       FOR X = 896 TO 927
0200       READ P
0210       POKE X,P
0220       NEXT
0230       DATA    169,3,160,138,32,217,3,96,0,0,1,96,2,0,0,0,155,3,0,96,0,
            0,1,0,0,96,1,0,1,239,216,118
0240 REM
0250 REM     INITIAL VARIABLE
0260 REM
0270       T = 910
0280       S = 911
0290       FOR I = 1 TO 12
0300       READ AD(I)
0310       NEXT
0320       DATA   31,28,31,30,31,30,31,31,30,31,30,31
0330 REM
0340 REM    CALL SUBROUTINE TO CHECK NUMBER OF CHANNEL IN THE
0350 REM    DISK AND CHECK WHETHER IT IS A DATA DISK.
0360 REM
0370       GOSUB 1330
0380       PRINT "PLEASE TURN THE PRINTER ON AND WAIT "
0390       IN = 34 / NC
0400       ST = 0
0410       EN = IN * 16 - 1
0420 REM
0430 REM     LOAD FORMAT ROUTINE IN MEMORY
0440 REM
0450       PRINT  CHR$ (4)"BRUN  PRINTUSR,A$94A0"
0460 REM
0470 REM      RETRIEVE ALL THE POSSIBLE DATA STORED IN THE DISK
0480 REM
0490       FOR II = 0 TO EN
0500       IF (ST = 16) THEN ST = 0:TR = TR + 1
0510       PRINT  CHR$ (4)"PR#1"
0520       FOR K = 1 TO NC
0530       POKE T,TR + (K - 1) * IN
0540       POKE S,ST
0550       CALL 896
0560 REM
0570 REM     READ THE TIME OF THE FIRST READING AND CONVERT THE
0580 REM   TIME INTO NUMERCIAL VALUE
0590 REM
0600       T2$ = ""
```

```
0610      IF ( PEEK (24576) = 0 AND  PEEK (24577) = 0) THEN  END
0620      FOR I = 1 TO 14
0630      A$ =  CHR$ ( PEEK (24575 + I))
0640      IF (I = 9 OR I = 12) THEN A$ = ":"
0650      T2$ = T2$ + A$
0660      NEXT
0670      D(1) =  VAL ( LEFT$ (T2$,2))
0680      D(2) =  VAL ( MID$ (T2$,4,2))
0690      D(3) =  VAL ( MID$ (T2$,7,2))
0700      D(4) =  VAL ( MID$ (T2$,10,2))
0710      D(5) =  VAL ( MID$ (T2$,13,2))
0720 REM
0730 REM     READ IN ALL THE DATA IN THE TRACK
0740 REM
0750      FOR I = 0 TO 39
0760      B(K,I) = 0
0770      TP = 0
0780      JJ = 10
0790      FOR J = 2 TO 6
0800      A =  PEEK (24591 + I * 6 + J)
0810      A = A - 176
0820      IF (J = 3) THEN  NEXT J
0830      JJ = JJ / 10
0840      B(K,I) = B(K,I) + A * JJ
0850      NEXT
0860      B(K,I) = B(K,I) * C(K)
0870      NEXT
0880      NEXT
0890 REM
0900 REM     PRINT THE TITLE, THE TIME AND ALL THE DATA RECORDED
0910 REM   IN EACH CHANNEL.
0920 REM
0930      PRINT
0940      PRINT  CHR$ (12)
0950      PRINT  TAB( 3)
0960      PRINT "FIRST READING'S TIME       :       ";T2$
0970      PRINT  TAB( 3)
0980      PRINT "TIME BETWEEN EACH READING  :       ";SC;" SEC."
0990      PRINT
1000      FOR K = 1 TO NC
1010      PRINT  TAB( 3)
1020      PRINT "TITLE OF CHANNEL "; USR (K)'2,0';" :
              ";B$(K);" (";C$(K);")"
1030      NEXT
1040      PRINT
1050      PRINT "TIME ";
1060      FOR K = 1 TO NC
1070      PRINT  TAB( 4): PRINT  USR (K)'4,0';
1080      NEXT
1090      PRINT
1100      FOR I = 0 TO 39
1110      PRINT  USR (D(3))'2,0';":"; USR (D(4));
1120      FOR K = 1 TO NC
1130      PRINT  USR (B(K,I))'7,1';
1140      NEXT
1150 REM
1160 REM     DETERMINE THE NEXT READING TIME OF THE DATA.
1170 REM
1180      D(5) = D(5) + SC
1190      IF (D(5) > = 60) THEN D(4) = D(4) +  INT (D(5) / 60):
           D(5) = D(5) -  INT (D(5) / 60) * 60
```

```
1200      IF (D(4) > = 60) THEN D(3) = D(3) +  INT (D(4) / 60):
           D(4) = D(4) -  INT (D(4) / 60) * 60
1210      IF (D(3) > = 24) THEN D(2) = D(3) +  INT (D(3) / 24):
           D(3) = D(3) -  INT (D(3) / 24) * 24
1220      IF (D(2) > AD(D(1))) THEN D(2) = 1:D(1) = D(1) + 1
1230      IF (D(1) = 13) THEN D(1) = 1
1240      PRINT
1250      NEXT
1260      ST = ST + 1
1270      NEXT
1280      END
1290 REM
1300 REM     READ IN NUMBER OF CHANNEE AND CHECK WHETHER THE DISK
1310 REM   IS FOR DATA ACQUISITION STORAGE.
1320 REM
1330      I = 1
1340      ST = 0
1350      POKE T,34
1360      POKE S,ST
1370      CALL 896
1380      NC =  PEEK (24576)
1390      SC =  PEEK (24584) * 10000 +  PEEK (24585) * 100 +  PEEK (24586)
1400      SC = 900
1410      IF (NC < = 0 OR NC > 10) THEN  PRINT "WRONG DISK": END
1420      FOR II = 1 TO NC
1430      FOR J = 1 TO 32
1440      TP$ =  CHR$ ( PEEK (24591 + (I - 1) * 64 + J))
1450      IF (TP$ = "") THEN  GOTO 1480
1460      B$(II) = B$(II) + TP$
1470      NEXT
1480      FOR J = 1 TO 16
1490      TP$ =  CHR$ ( PEEK (24623 + (I - 1) * 64 + J))
1500      IF (TP$ = "") THEN  GOTO 1530
1510      C$(II) = C$(II) + TP$
1520      NEXT
1530      C(II) =  PEEK (24639 + (I - 1) * 64 + 1) * 100 +  PEEK (24639 + (
           I - 1) * 64 + 2)
1540      IF ( INT (II / 3) * 3  < > II) THEN I = I + 1: GOTO 1590
1550      ST = ST + 1
1560      POKE 911,ST
1570      CALL 896
1580      I = 1
1590      NEXT
1600      HOME
1610      PRINT "NUMBER OF CHANNEL ";NC
1620      RETURN
```

APPENDIX C

```
BASIC
APPLESOFT BASIC                                          PAGE 1

0010 REM
0020 REM      THIS PROGRAM PREDICT AMBIENT TEMPERATURE AND
0030 REM    DETERMINE WHETHER NORMAL OR ABNORMAL WEATHER.
0040 REM
0050 DIM  XG(12).YG(12),XB(12),YB(12),X(48),Y(48)
0060 REM
0070 REM    SYMBOLS
0080 REM      XG = TIME OF NORMAL WEATHER DATA.
0090 REM      YG = AMBIENT TEMPERATURE OF NORMAL WEATHER DATA.
0100 REM      XB = TIME OF WEATHER FRONT DATA.
0110 REM      YB = AMBIENT TEMPERATURE OF WEATHER FRONT DATA.
0120 REM
0130 REM
0140 REM      INITIAL VARIABLE
0150 REM
0160 OM = 0.261799392
0170 D$ =  CHR$ (4)
0180 REM
0190 REM      DEFINE FUNCTION EA AND EB TO CALCULATE AMBIENT
0200 REM    TEMPERATURE.
0210 REM
0220 DEF  FN EA(W) = C1 + C2 *  SIN (OM * W + 3 * TH) + C3 *  SIN (2 *
           OM * W + TH)
0230 DEF  FN EB(W) = C4 + C2 *  SIN (OM * W + 3 * TH) + C3 *  SIN (2 *
           OM * W + TH)
0240 REM
0250 REM      READ NORMAL WEATHER DATA FROM FILE DATA2.
0260 REM
0270 PRINT D$;"OPEN DATA2": PRINT D$;"READ DATA2": INPUT BD:
           FOR I = 1 TO 11: INPUT XG(I),YG(I): NEXT :
           PRINT D$;"CLOSE DATA2"
0280 REM
0290 REM      READ IN NEW WEATHER DATA FROM FILE DATA1.
0300 REM
0310 PRINT D$;"OPEN DATA1": PRINT D$;"READ DATA1": INPUT T$:
           INPUT YG(12): PRINT D$;"CLOSE DATA1":
          XG(12) =  VAL ( MID$ (T$,7,2))
0320 PRINT D$;"OPEN DATA0": PRINT D$;"READ DATA0": FOR I = 1 TO 48:
           INPUT X(I),Y(I): NEXT : PRINT D$;"CLOSE DATA0"
0330 REM
0340 REM      DETERMINE WHICH MONTH THE NEW DATA IS NOW AND DETERMINE
0350 REM    THE COEFFICIENT OF THE THEORETICAL CURVE.
0360 REM
0370 NN =  VAL ( LEFT$ (T$,2))
0380 RESTORE
0390 FOR I = 1 TO NN
0400 READ C1,C2,C3,TH
0410 NEXT
0420 REM
0430 REM      ADJUST THE COEFFICIENT OF THE VARIABLE IF THE DATE
0440 REM    IS AT THE FIRST AND LAST FEW DAYS OF THE MONTH.
0450 REM
0460 IF ( VAL ( MID$ (T$,4,2)) <  = 8) THEN NN =  VAL ( LEFT$ (T$,2))
          - 1: IF (NN = 0) THEN NN = 12
0470 IF ( VAL ( MID$ (T$,4,2)) =  > 23) THEN NN =  VAL ( LEFT$ (T$,2))
          + 1: IF (NN = 13) THEN NN = 1
0480 RESTORE : IF (NN <  >  VAL ( LEFT$ (T$,2))) THEN  FOR I = 1 TO NN:
           READ T1,T2,T3,T4: NEXT :C1 = (C1 + T1) / 2:C2 = (C2 + T2) / 2:
          C3 = (C3 + T3) / 2:TH = (TH + T4) / 2
0490 REM
0500 REM      CALCULATE THE MEAN TEMPERATURE OF THE FIRST SET OF DATA.
```

```
BABIC
APPLESOFT BASIC                                        PAGE 2

0510 REM
0520 SM = 0
0530 FOR I = 1 TO 6
0540 SM = SM + (YG(I) -  FN EA(XG(I)))
0550 NEXT
0560 C4 = C1 + SM / 6
0570 REM
0580 REM     DETERMINE THE STANDARD DEVIATION OF THE SECOND SET DATA
0590 REM   WITH RESPECT TO THE FIRST SET DATA'S CURVE.
0600 REM
0610 SM = 0
0620 FOR I = 7 TO 12
0630 TP = (YG(I) -  FN EB(XG(I)))
0640 SM = SM + TP ^ 2
0650 NEXT
0660 TP =  SQR (SM / 5)
0670 REM
0680 REM     IF THE DEVIATION IS GREATER THAN 1.6 THEN ABNORMAL
0690 REM   WEATHER ENCOUNTER.
0700 REM
0710 IF (TP > 1.6) THEN : GOTO 940
0720 REM
0730 REM         NORMAL WEATHER
0740 REM     DETERMINE THE MEAN TEMPAERATUER OF ALL THE PAST DATA.
0750 REM   UPDATE THE DATA AND STORE BACK IN THE FILE.
0760 REM
0770 SM = 0
0780 FOR I = 1 TO 12
0790 SM = SM + (YG(I) -  FN EA(XG(I)))
0800 NEXT
0810 C4 = C1 + SM / 12
0820 IF ((Y(7) -  FN EB(X(7))) < 1.5) THEN  FOR I = 1 TO 6:
          XG(I) = XG(I + 1):YG(I) = YG(I + 1): NEXT
0830 FOR I = 7 TO 11
0840 XG(I) = XG(I + 1)
0850 YG(I) = YG(I + 1)
0860 NEXT : GOSUB 1250: PRINT  TAB( 15): PRINT "(NORMAL WEATHER)":
          PRINT : PRINT : PRINT D$;"PR#"
0870 PRINT D$;"OPEN DATA2": PRINT D$;"DELETE DATA2":
          PRINT D$;"OPEN DATA2": PRINT D$;"WRITE DATA2": PRINT BD:
          FOR I = 1 TO 11: PRINT XG(I);",";YG(I): NEXT :
          PRINT D$;"CLOSE DATA2"
0880 PRINT D$;"RUN INCREASE1": END
0890 REM
0900 REM          ABNORMAL WEATHER
0910 REM     STORE THE ABNORMAL DATA IN FILE DATAB AND CHECK
0920 REM   WHETHER THE WEATHER RETURN TO NORMAL WEATHER.
0930 REM
0940 IF (BD <  > 0) THEN  PRINT D$;"OPEN DATAB": PRINT D$;"READ DATAB":
          FOR I = 1 TO BD: INPUT XB(I),YB(I): NEXT : PRINT D$"CLOSE DATAB
0950 TE = C4
0960 IF (BD < 12 AND BD <  > 0) THEN SM = 0: FOR I = 1 TO BD:
          SM = SM + (YB(I) -  FN EA(XB(I))): NEXT :C4 = C1 + SM / BD
0970 IF (BD = 0) THEN  FOR I = 7 TO 11:XB(I - 6) = XG(I):
          YB(I - 6) = YG(I): NEXT :BD = 5
0980 IF (BD = 12) THEN SM = 0: FOR I = 1 TO 12:
          SM = SM + (YB(I) -  FN EA(XB(I))): NEXT :C4 = C1 + SM / 12:
          SM = 0: FOR I = 1 TO 12:TP = YB(I) -  FN EB(XB(I)):
          SM = SM + TP ^ 2: NEXT :TP =  SQR (SM / 12)
0990 IF (BD = 12 AND TP < 0.16) THEN  FOR I = 1 TO 6:XG(I) = XB(I):
          YG(I) = YB(I): NEXT : GOTO 460
```

BASIC
APPLESOFT BASIC PAGE 3

```
1000 IF (BD = 12 AND TP > 0.16) THEN  FOR I = 1 TO 11:
           XB(I) = XB(I + 1):YB(I) = YB(I + 1): NEXT :BD = 11
1010 C4 = TE
1020 BD = BD + 1:XB(BD) = XG(12):YB(BD) = YG(12): GOSUB 1250:
            PRINT  TAB( 15): PRINT "(WEATHER FRONT)": PRINT : PRINT :
            PRINT D$;"PR#"
1030 REM
1040 REM     UPDATE THE ABNORMAL WEATHER DATA AND NORMAL WEATHER
1050 REM    DATA IN FILES.
1060 REM
1070 PRINT D$;"OPEN DATAB": PRINT D$;"DELETE DATAB":
            PRINT D$;"OPEN DATAB": PRINT D$;"WRITE DATAB": FOR I = 1 TO BD:
            PRINT XB(I);",";YB(I): NEXT : PRINT D$"CLOSE DATAB"
1080 FOR I = 7 TO 11
1090 XG(I) = XG(I + 1)
1100 YG(I) = YG(I + 1)
1110 NEXT
1120 PRINT D$;"OPEN DATA2": PRINT D$;"DELETE DATA2":
            PRINT D$;"OPEN DATA2": PRINT D$;"WRITE DATA2": PRINT BD:
            FOR I = 1 TO 11: PRINT XG(I);",";YG(I): NEXT :
            PRINT D$;"CLOSE DATA2"
1130 PRINT D$;"RUN INCREASE1": END
1140 REM
1150 REM     PREDICTION COEFFIECIENT OF EACH MONTH.
1160 REM
1170 DATA  3.375,2.7965,0.84673,1.1963,4.3958,3.9776,1.0081,1.1910,4.
           9625,4.4616,.90124,1.2429
1180 DATA  6.5833,5.9201,.67013,1.2640,8.3333,7.4836,.55940,1.2668,7.9
           375,7.1147,.58829,1.2951
1190 DATA 7.7292,7.2255,.70749,1.2798,8.1458,7.6278,1.0580,1.3085,6.42
           92,6.5738,1.1554,1.2958
1200 DATA  5.5833,5.2327,1.4642,1.2975,2.9917,2.9089,.94649,1.2820,2.2
           167,1.9793,.71858,1.2422
1210 REM
1220 REM     DISPLAY THE PREDICTION CURVE AS WELL AS
1230 REM    THE ACTUAL DATA ON THE SCREEN.
1240 REM
1250 HGR : HCOLOR= 3: HPLOT 30,10 TO 30,150: HPLOT  TO 246,150:
            FOR I = 39 TO 254 STEP 9: HPLOT I,147 TO I,153: NEXT
1260 VTAB (7): PRINT " 20": VTAB (13): PRINT " 10": VTAB (19):
            PRINT "  0"
1270 VTAB (21): HTAB (4): FOR I = 1 TO 48 STEP 6:
            IF (X(I) < 10) THEN  PRINT "0";
1280 PRINT X(I);"  ";: NEXT : IF (X(1) < 10) THEN  PRINT "0";
1290 PRINT X(1): VTAB (23): HTAB (5):
            PRINT "TEMPERATURE PREDICTION AT ";X(12);":00"
1300 FOR I = 10 TO 140 STEP 10: HPLOT 27,I TO 33,I: NEXT
1310 FOR I = X(1) TO X(1) + 48 STEP 1:II = 30 + (I - X(1)) * 4.5:
           II =  INT (II):J =  FN EB(I):JJ = 150 - J * 5
1320 IF (I = X(1)) THEN  HPLOT II,JJ
1330 IF (I <  > X(1)) THEN  HPLOT  TO II,JJ
1340 NEXT
1350 FOR I = 1 TO 12:TX = 30 + (X(I) - X(1)) * 4.5:TX =  INT (TX):
            IF TX < 30 THEN TX = TX + 24 * 4.5
1360 TY = 150 - Y(I) * 5: GOSUB 1420: NEXT I
1370 FOR I = 13 TO 24:TX = 30 + (X(I) - X(1)) * 4.5:TX =  INT (TX):
            IF TX < 30 THEN TX = TX + 24 * 4.5
1380 TY = 150 - Y(I) * 5: GOSUB 1430: NEXT
1390 FOR I = 25 TO 48:TX = 138 + (X(I) - X(1)) * 4.5:TX =  INT (TX):
            IF TX < 138 THEN TX = TX + 24 * 4.5
1400 TY = 150 - Y(I) * 5: GOSUB 1430: NEXT
```

```
1410 PRINT D$;"PR#1": PRINT  CHR$ (17): RETURN
1420 HPLOT TX,TY: FOR II =  - 1 TO 1: FOR JJ =  - 1 TO 1:
            HPLOT  TO TX - II,TY - JJ: NEXT : NEXT : RETURN
1430 HPLOT TX - 1,TY TO TX + 1,TY: HPLOT TX,TY - 1 TO TX,TY + 1
1440 RETURN
```

APPENDIX D

Mode 1 (SW1, SW2 closed)

Between sunrise and sunset time $tsr < t < tss$

$$I1 = S1 * SIN[w1*(t-tsr)] \quad (D.1)$$

$$I3 - I2 = IG \quad (D.2)$$

where IG = Hourly recalculated internal gain and assume to be constant within that hour.

Consider loop ABDE $\Sigma V = 0$

$$\frac{1}{C} \int (I2 - I1)dt + R_C(I2 - I1) + R_{LS}*I2 + R_{AL}*I3 + TA(t) = 0 \quad (D.3)$$

From eq. D.2 $\quad I3 = IG + I2 \quad$ (D.4)

Substitute eq. D.1 & eq. D.4 into eq. D.3

$$\frac{1}{C} \int \{I2 - S1*SIN[w1*(t-tsr)]\}dt + R_C*\{I2 - S1*SIN[w1*(t-tsr)]\} + R_{LS}*I2 + R_{AL}*(IG+I2) + TA(t) = 0 \quad (D.5)$$

Differential w.r.t. time for eq. D.5

$$\frac{1}{C}\{I2 - S1*SIN[w1*(t-tsr)]\} + R_C \frac{dI2}{dt} - R_C \frac{d(S1*SIN[w1*(t-tsr)])}{dt} + R_{LS}\frac{dI2}{dt} + R_{AL}\frac{dI2}{dt} + \frac{dTA(t)}{dt} = 0$$

$$(R_C+R_{LS}+R_{AL})\frac{dI2}{dt} + \frac{1}{C} I2 = \frac{S1}{C} SIN[w1*(t-tsr)] + R_C*S1*w1*COS[w1*(t-tsr)] - \frac{dTA(t)}{dt}$$

$$(R_C+R_{LS}+R_{AL})\frac{dI2}{dt} + \frac{1}{C} I2 = \frac{1}{C}\{S1*SIN[w1*(t-tsr)] + R_C*C*S1*w1*COS[w1*(t-tsr)] - C\frac{dTA(t)}{dt}\}$$

$$\frac{dI2}{dt} + \frac{1}{C*(R_{LS}+R_{AL}+R_C)} I2 = \frac{1}{C*(R_{LS}+R_{AL}+R_C)}\{S1*SIN[w1(t-tsr)] + R_C*C*S1*w1*COS[w1*(t-tsr)] - C\frac{dTA(t)}{dt}\}$$

Let $\alpha = \dfrac{1}{C * (R_C+R_{LS}+R_{AL})}$

$$\frac{dI2}{dt} + \alpha * I2 = \alpha * \left\{ S1*B*SIN[w1*(t-tsr) + \phi_1] - C \frac{dTA(t)}{dt} \right\} \quad (D.7)$$

Where :

$$B = \sqrt{(R_C*C*w1)^2 + 1}$$

$$\phi_1 = TAN^{-1}(R_C*C*w1)$$

The complementary solution of eq. D.7

$$I2_c = A * e^{-\alpha t}$$

Where :

$$\alpha = 1/[(\Sigma R)*C) = 1/\text{time constant}$$

To find particular solution

First find $\dfrac{dTA(t)}{dt}$

Given from chapter 2

$$TA(t) = C(1) + C(2)*SIN(w*t+3*\theta) + C(3)*SIN(2*w*t+\theta)$$

$$\frac{dTA(t)}{dt} = C(2)*w*COS(w*t+3*\theta) + 2*w*C(3)*COS(2*w*t+\theta)$$

Therefore eq. D.7 becomes

$$\frac{dI2}{dt} + \alpha*I2 = \alpha*\{S1*B*SIN[w1*(t-tsr)+\phi_1] - C*w*[C(2)*COS(w*t+3*\theta) + 2*C(3)*COS(w*t+\theta)]\}$$

From mathematics table [2], the particular solution

$$I2_p = \alpha*S1*B\left\{\frac{\alpha*SIN[w1*(t-tsr)+\phi_1] - w1*COS[w1*(t-tsr)+\phi_1]}{(\alpha^2 + w1^2)}\right\} - w*\alpha*C\left\{C(2)\frac{\alpha*COS(w*t+3*\theta) + w*SIN(w*t+3*\theta)}{(\alpha^2 + w^2)} + C(3)\frac{\alpha*COS(2*w*t+\theta) + 2*w*SIN(2*w*t+\theta)}{(\alpha^2 + (2*w)^2)}\right\}$$

$$I2_p = \alpha*S1*B\left\{\frac{SIN[w1*(t-tsr)+\phi_1 - \phi_2]}{\sqrt{(\alpha^2 + w1^2)}}\right\} - w*\alpha*C\left\{\frac{C(2)*SIN[w*t+3*\theta + \phi_3]}{\sqrt{(\alpha^2 + w^2)}} + \frac{2*C(3)*SIN[2*w*t+\theta + \phi_4]}{\sqrt{(\alpha^2 + (2*w)^2)}}\right\}$$

The general solution

$$I2 = I2_c + I2_p$$

$$I2 = A\,e^{-\,t} + \alpha * S1 * B\left\{ \frac{SIN[w1*(t-tsr)+\phi_1 - \phi_2]}{\sqrt{(\alpha^2 + w1^2)}} \right\} - w*\alpha*C \left\{ \frac{C(2)*SIN[w*t+3*\theta + \phi_3]}{\sqrt{(\alpha^2 + w^2)}} + \frac{2*C(3)*SIN[2*w*t+\theta + \phi_4]}{\sqrt{(\alpha^2 + (2*w)^2)}} \right\} \quad (D.8)$$

Where:

A is obtained essentially as a boundary condition, by sustituting eq. D.8 in D.2, and eliminating I2, I3 and S1 with the current measurements for TR, TA and S1, as shown below

$$\alpha = \frac{1}{(\Sigma R) * C} = \frac{1}{\text{Time constant}}$$

$$B = \sqrt{[(R_C*c*w1)^2 + 1]}$$

C(2), C(3), θ = Curvefitted coefficient from past weather data

$$\phi_1 = TAN^{-1}[R_C*C*w1]$$

$$\phi_2 = TAN^{-1}[\frac{w1}{\alpha}]$$

$$\phi_3 = TAN^{-1}[\frac{\alpha}{w}]$$

$$\phi_4 = TAN^{-1}[\frac{\alpha}{2*w}]$$

$$w1 = \pi/(tsr - tss)$$

$$w = 2 * \pi/24$$

IG = Heat gains or losses from other sources

I2 = Heat flow through the room.

A is obtained by substituting equation D.8 in D.2 and I3 can be expressed as:

$$I3 = IG + A\ e^{-\alpha t} + \alpha*S1*B\{\frac{SIN[w1*(t-tsr)+\phi_1 - \phi_2]}{\sqrt{(\alpha^2 + w1^2)}}\} -$$

$$w*\alpha*C\ \{\frac{C(2)*SIN[w*t+3*\theta + \phi_3]}{\sqrt{(\alpha^2 + w^2)}} +$$

$$\frac{2*C(3)*SIN[2*w*t+\theta + \phi_4]}{\sqrt{(\alpha^2 + (2*w)^2)}}\}$$

From figure 3.3

$$I3 = \frac{TR - TA}{R_{AL}}$$

Then

$$A\ e^{-\alpha t} = \frac{TR - TA}{R_{AL}} - IG - \alpha*S1*B\left\{\frac{SIN[w1*(t-tsr)+\phi_1 - \phi_2\ ]}{\sqrt{(\alpha^2 + w1^2)}}\right\} +$$

$$w*\alpha*C\left\{\frac{C(2)*SIN[w*t+3*\Theta\ +\phi_3\ ]}{\sqrt{(\alpha^2 + w^2)}} +\right.$$

$$\left.\frac{2*C(3)*SIN[2*w*t+\Theta + \phi_4\ ]}{\sqrt{(\alpha^2 + (2*w)^2)}}\right\} \qquad (D.9)$$

With the current measurements for TR, TA and S1 (S1 = 0 for no solar input) then A can be calculated.

Mode 2 (SW1 opened & SW2 closed)

A similiar solution, as shown below, is obtained either performing the above calculation for mode 1 or substituting S1 = 0.

$$I2 = A\ e^{-\alpha t} -$$

$$w^{*}\ \alpha\ {*}C\ \left\{ \frac{C(2)*SIN[w*t+3*\theta + \phi_3]}{\sqrt{(\alpha^2 + w^2)}} + \frac{2*C(3)*SIN[2*w*t+\theta+\phi_4]}{\sqrt{(\alpha^2 + (2*w)^2)}} \right\} \qquad (D.10)$$

and I3 = I2 + IG

Mode 3 (SW1, SW2 opened)

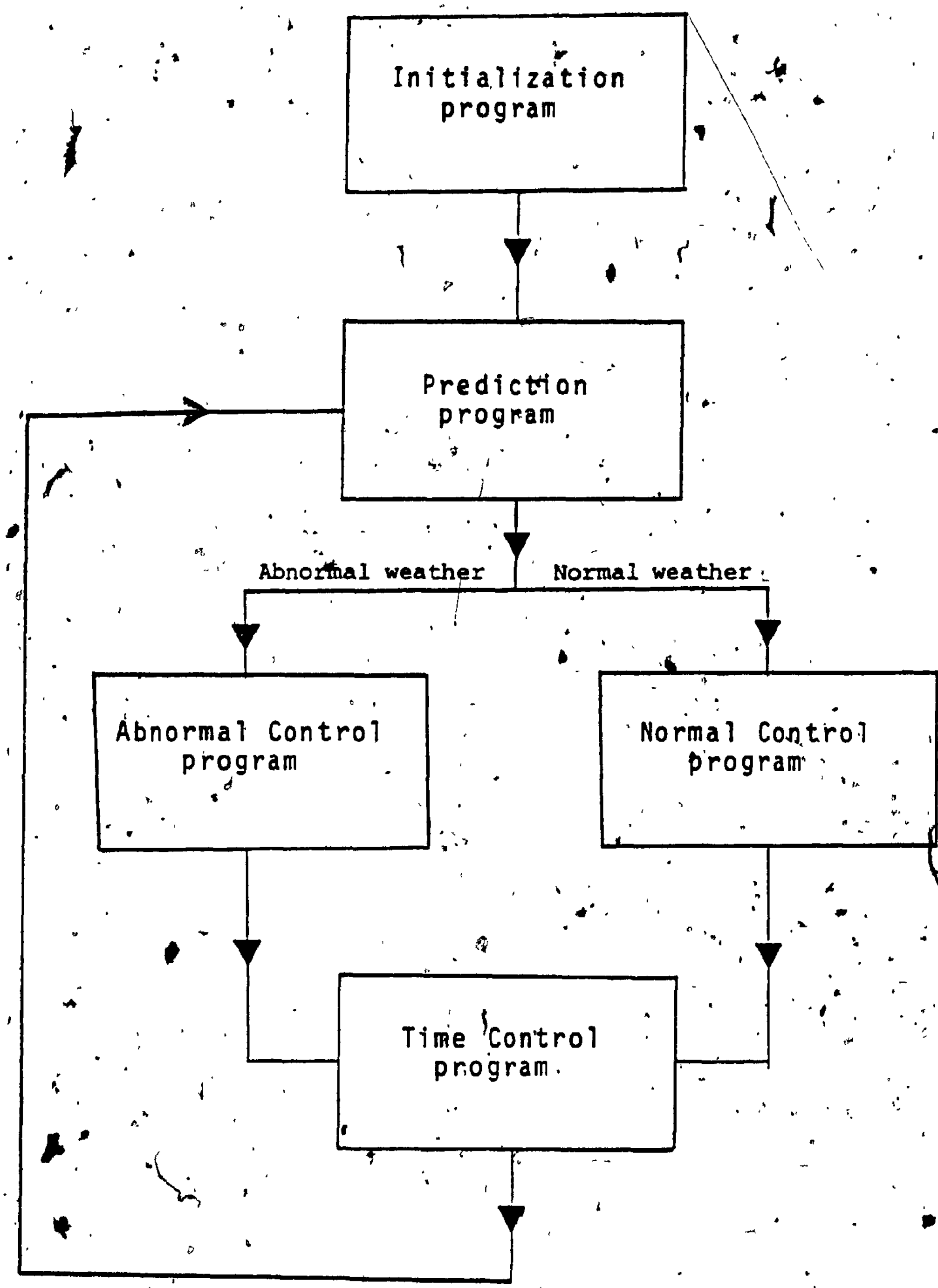
A similiar solution, as shown below, is obtained either performing the above calculation for mode 1 or substituting S1 = 0 and IG = 0.

$$I2 = A\, e^{-\alpha t} -$$

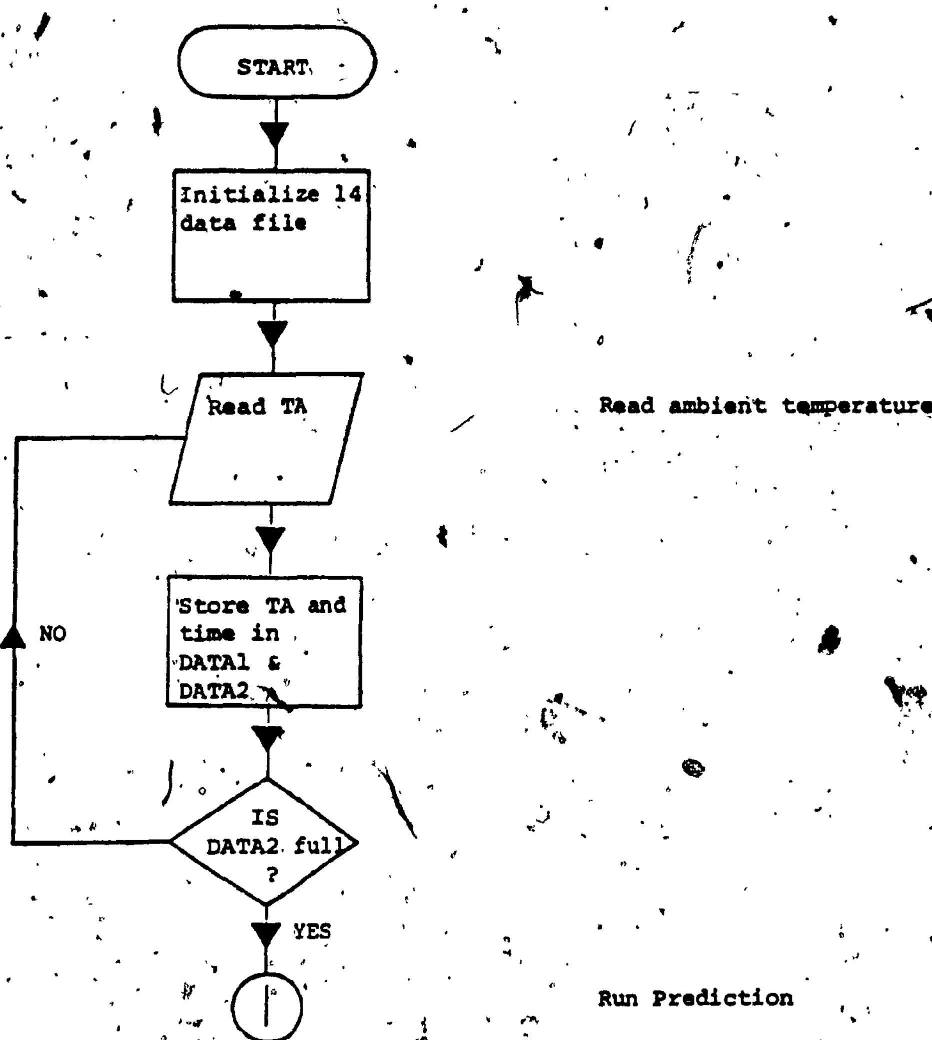
$$w^* \alpha ^* C \left\{ \frac{C(2)^* SIN[w^* t + 3^* \theta + \phi_3]}{\sqrt{(\alpha^2 + w^2)}} + \frac{2^* C(3)^* SIN[2^* w^* t + \theta + \phi_4]}{\sqrt{(\alpha^2 + (2^* w)^2)}} \right\} \tag{D.11}$$

and I3 = I2

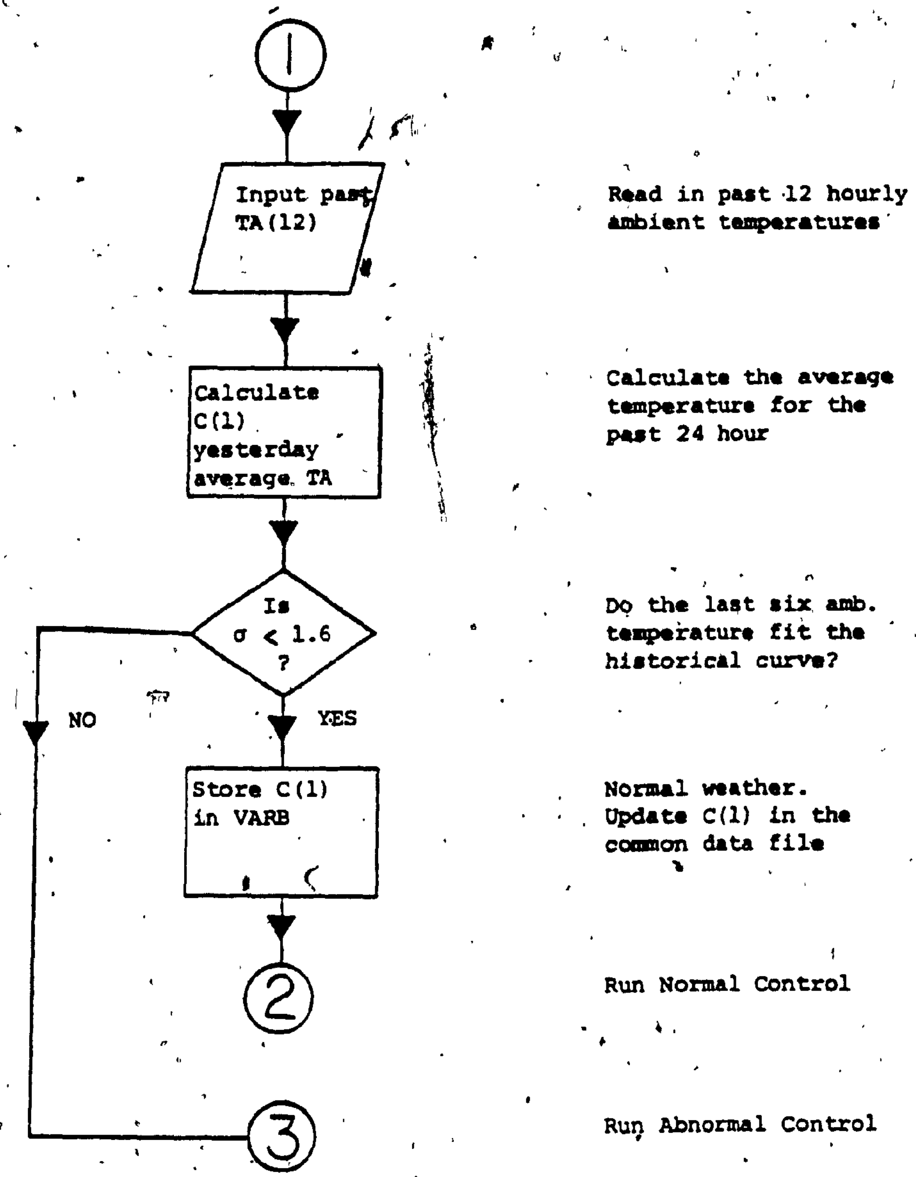
APPENDIX E



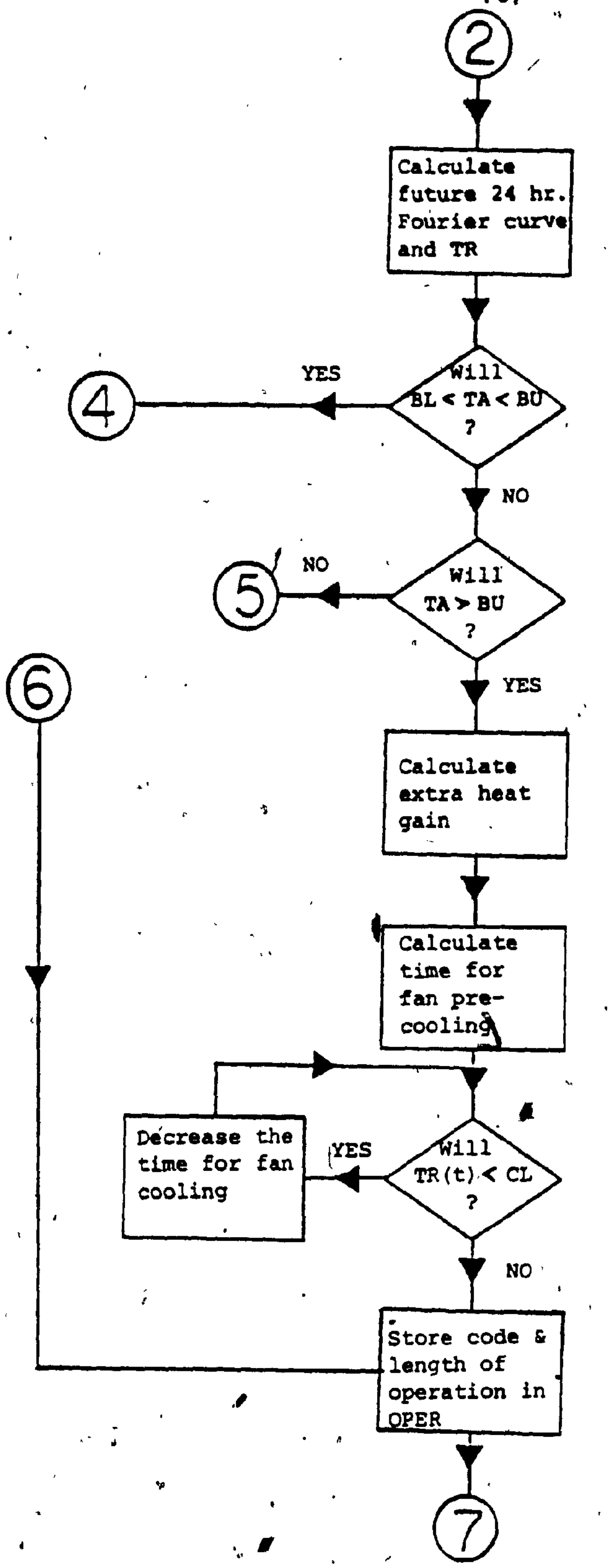
On Line Predictive Control program flowchart



Initialization program



Prediction program



Predict next 24 hour amb. temperature & calculate next 24 hour room temperature

Is ambient temperature between the heating & cooling balance points all day tomorrow?

Will ambient temp. exceed the cooling balance temperature?

Calculate extra heat gain to be offset by pre-cool

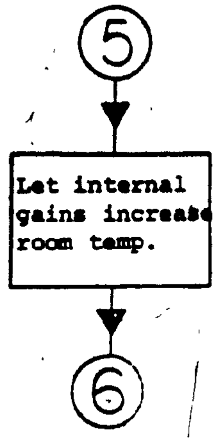
Calculate the time required for pre-cooling

Is pre-cooling creates a demand for heating at night decrease the amount of pre-cooling

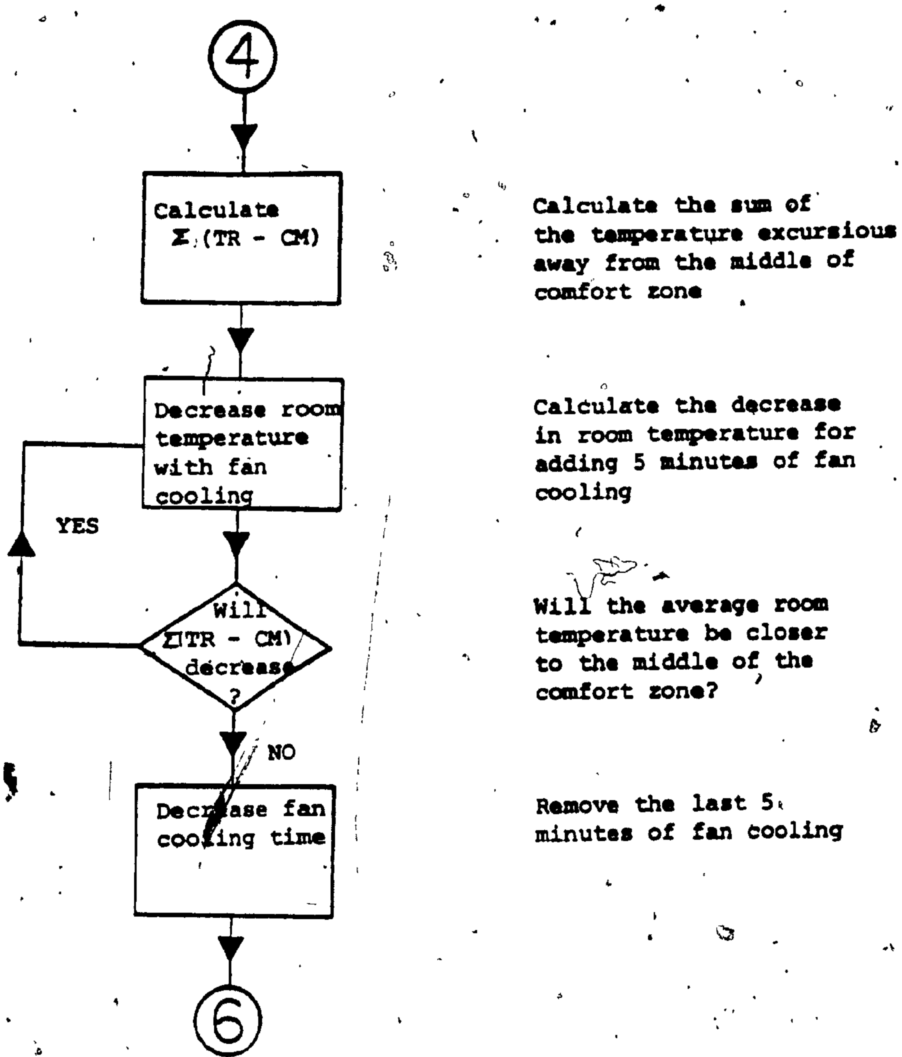
Store operation code and length of operation in OPER file
0 all off
1 pre-cool
4 move to centre of comfort zone

Run Time Control

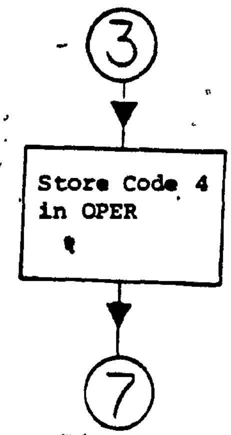
Normal Control program (1/3)



Normal Control program (2/3)



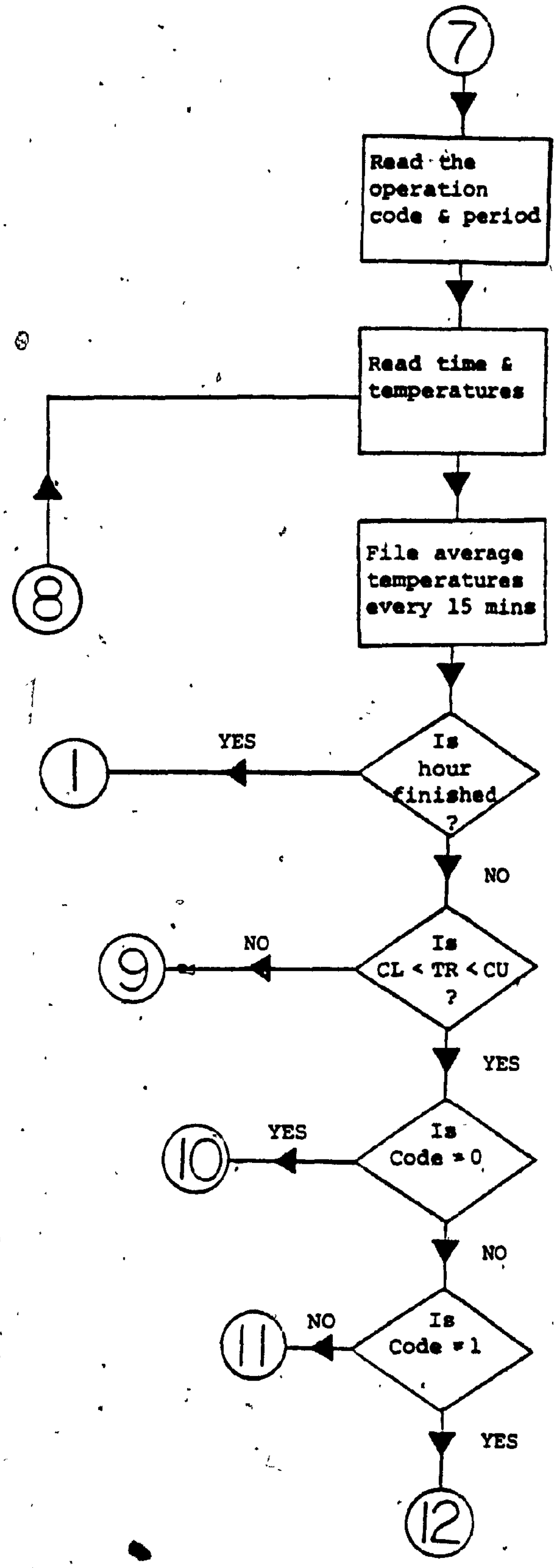
Normal Control program (3/3)



Store mode code in
OPER file
0 all system off
1 pre-cooling
4 abnormal weather

Run Time Control

Abnormal Control program



Read the chosen operation code & time period from OPER (0, 1 or 4)

Read time from the clock & 9 temperatures from data acquisition

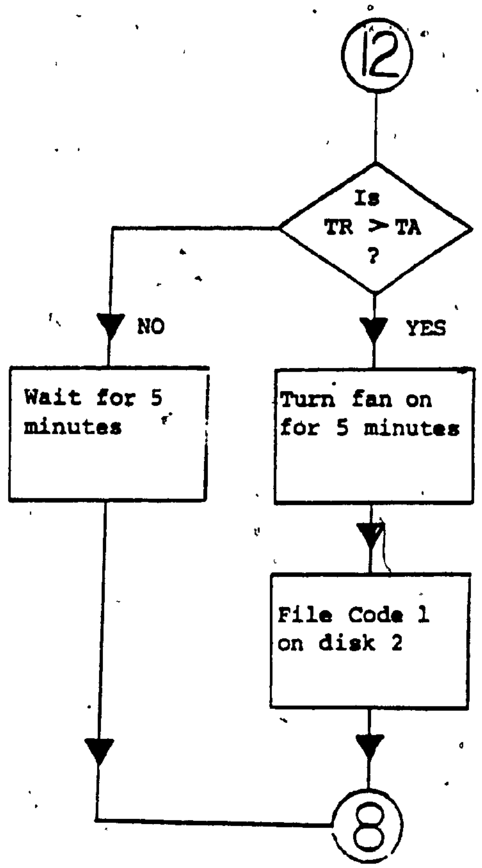
Branch to Prediction every hour

Normal thermostat action: If room temperature is outside the comfort zone, turn on heater or air-conditioner for 5 mins.

For Code 0, heat with internal gains for 5 minutes

For Code 1, cool with fan, if possible for 5 minutes

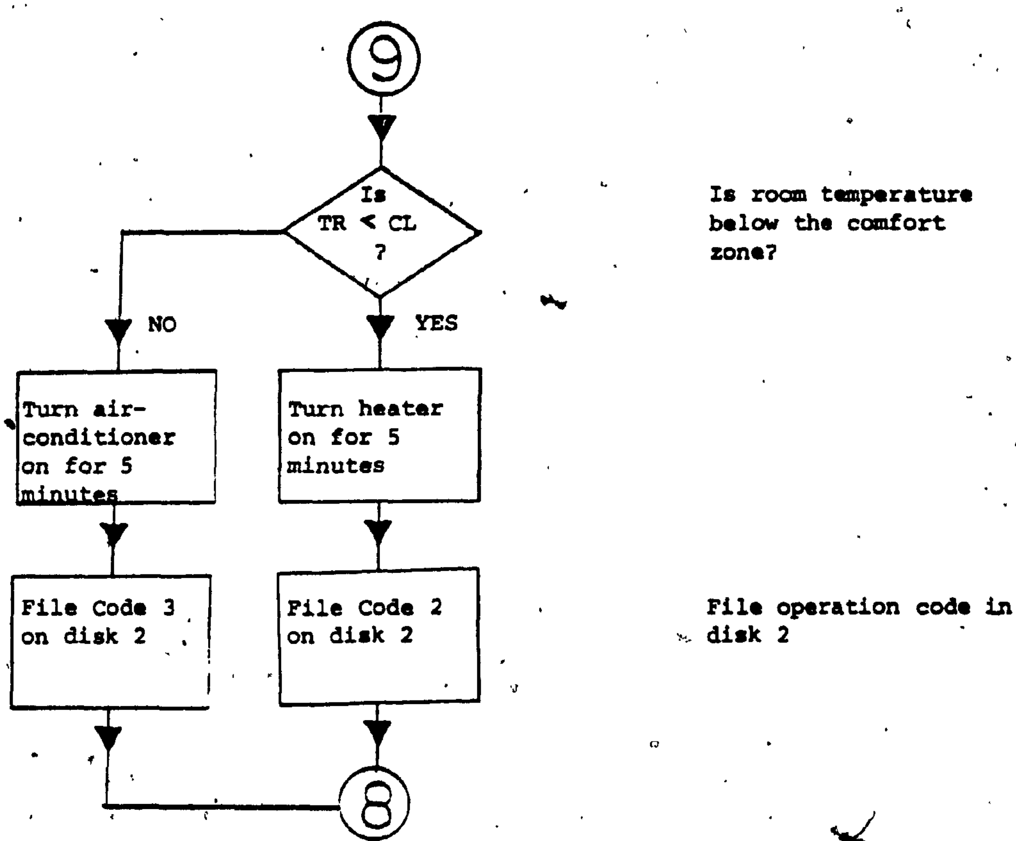
Time Control program (1/5)



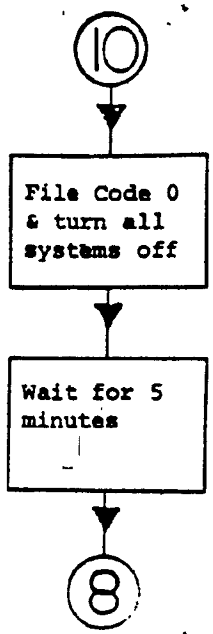
For Code 1, turn on fan for 5 minutes unless ambient temperature is too high

File fan operation Code on disk 2 & reduce duration in OPER and RAM

Time Control program (2/5)

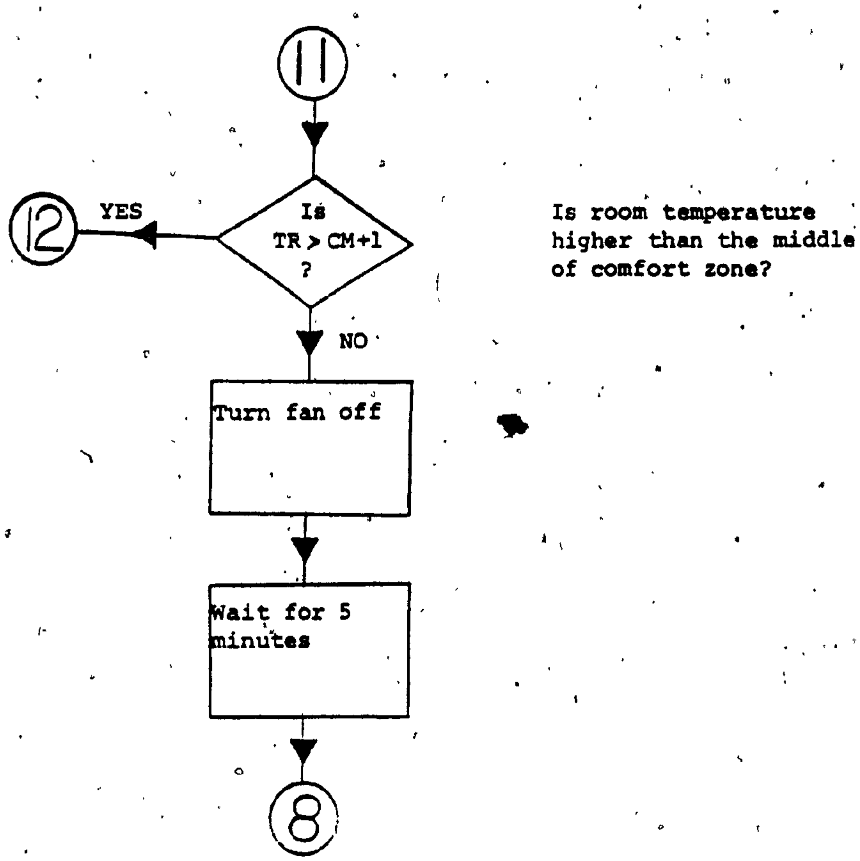


Time Control program (3/5)



File 0 operation code on disk 2 & turn all systems off

Time Control program (4/5)



Time Control program (5/5)

```
BASIC
APPLESOFT BASIC                                               PAGE 1

0010 REM
0020 REM                  INITIALIZATION PROGRAM
0030 REM
0040 REM   THIS PROGRAM CREATES COMMON DATA FILE BEFORE RETRIEVING
0050 REM   12 HOURS' WEATHER DATA
0060 REM
0070 D$ =  CHR$ (4): DIM TP(15),AD(12),A(12),T(15):SU(15)
0080 PRINT D$;"BRUN AA/DD.D1"
0090 Z = 1
0100 REM
0110 REM      GET TIME FROM INTERNAL CLOCK
0120 REM      CALL SUBROUTINE TO READ TIME DATA
0130 REM      TIME DATA IS IN 12 HOUR FORMAT AND CHARACTER FORM
0140 REM
0150 PRINT D$;"IN#4": PRINT D$;"PR#4": INPUT " ";T$: PRINT D$;"IN#0":
            PRINT D$;"PR#0"
0160 NC = 9
0170 FOR I = 0 TO NC - 1: PRINT D$;"OPEN CHANO";I:
            PRINT D$;"DELETE CHANO";I: PRINT D$;"WRITE CHANO";I:
            PRINT D$;"CLOSE CHANO";I: NEXT I
0180 GOSUB 410
0190 N3 = 1:SC = 300
0200 T(N3) =  VAL ( MID$ (T$,7,2)):A(N3) = TP(0)
0210 N3 = N3 + 1
0220 REM
0230 REM      CHECK FOR END OF DATA
0240 REM      IF END OF DATA THEN
0250 REM         CALL SUBROUTINE TO STORE TIME AND WEATHER
0260 REM      ELSE
0270 REM         CALL SUBROUTINE TO CONVERT TIME DATA TO NUMBER
0280 REM         WHEN CONVERSION COMPLETE CHECK FOR VALID TIME
0290 REM
0300 IF (N3 >  = 13) THEN  GOTO 350
0310 GOSUB 540
0320 PRINT D$;"IN#4": PRINT D$;"PR#4": INPUT " ";T1$: PRINT D$;"IN#0":
            PRINT D$;"PR#0": VTAB (5): HTAB (17): PRINT  LEFT$ (T1$,14)
0330 M1 =  VAL ( MID$ (T1$,1,2)):D1 =  VAL ( MID$ (T1$,4,2)):
          H1 =  VAL ( MID$ (T1$,7,2)):M2 =  VAL ( MID$ (T1$,10,2)):
          S1 =  VAL ( MID$ (T1$,13,2))
0340 IF (MT =  > M1) THEN  IF (D >  = D1) THEN  IF (H >  = H1) THEN  I
          F (M >  = M2) THEN  IF (S >  = S1) THEN  GOTO 320
0350 GOSUB 620: GOTO 320
0360 REM
0370 REM      SUBROUTINE:
0380 REM      -----------
0390 REM    READ IN DATA FROM DATA ACQUISITION
0400 REM
0410 POKE 49245,0: FOR K = 1 TO 800: NEXT K: POKE 49244,0:
           FOR K = 1 TO 500: NEXT K: FOR I = 0 TO NC - 1:
           FOR II = 1 TO 300: CALL 49664: NEXT II: PRINT I
0420 TP(I) = 0: FOR II = 3 TO 5:
          TP(I) = ( PEEK (49856 + II) - 176) / 10 ^ (II - 2) + TP(I):
           NEXT II:TP(I) = TP(I) + ( PEEK (49857) - 176)
0430 IF ( PEEK (49856) = 173) THEN TP(I) = TP(I) * 1.
0440 TP(I) = (TP(I) - 1.8) * 14.8: POKE 49241,0: FOR K = 1 TO 700:
           NEXT K: POKE 49240,0: FOR K = 1 TO 300: NEXT K: NEXT I: RETURN
0450 IF Z <  > 4 THEN  FOR I = 0 TO NC - 1:SU(I) = SU(I) + TP(I):
           NEXT I:Z = Z + 1: GOTO 190
0460 FOR I = 1 TO NC - 1:TP(I) = SU(I) / 4: NEXT I
0470 FOR I = 0 TO NC - 1: PRINT D$;"APPEND CHANO";I;",D2":
           PRINT D$;"WRITE CHANO";I
```

```
0480 PRINT  LEFT$ (T1$,14):TP$ =  STR$ (TP(I)): PRINT  LEFT$ (TP$,5)
0490 PRINT D$;"CLOSE CHANO";I: NEXT I
0500 GOTO 190
0510 REM
0520 REM      CHANGE THE CLOCK TIME FROM CHARACTERS TO NUMBERS.
0530 REM
0540 MT =  VAL ( MID$ (T$,1,2)):D =  VAL ( MID$ (T$,4,2)):
        H =  VAL ( MID$ (T$,7,2)):M =  VAL ( MID$ (T$,10,2)):
        S =  VAL ( MID$ (T$,13,2)):S = S + SC:M = M +  INT (S / 60)
0550 S = S -  INT (S / 60) * 60:H = H +  INT (M / 60):
        M = M -  INT (M / 60) * 60:D = D +  INT (H / 24):
        H = H -  INT (H / 24) * 24
0560 MT = MT +  INT (D / AD(MT)):D = D -  INT (D / AD(MT)) * AD(MT):
         IF (MT > 12) THEN MT = MT - 12
0570 RETURN
0580 REM
0590 REM        CREATE COMMON DATA FILES
0600 REM        STORE PAST 12 HOUR WEATHER INTO THE DATA FILES
0610 REM
0620 PRINT D$;"OPEN OPER,D2": PRINT D$;"DELETE OPER":
          PRINT D$;"OPEN OPER": PRINT D$;"WRITE OPER":
          PRINT D$;"CLOSE OPER"
0630 BD = 0:C4 = 0:C2 = 0:C3 = 0:TH = 0:TT = T(12):TA = A(12):
        TR = TP(3)
0640 PRINT D$;"OPEN VARB,D1": PRINT D$;"DELETE VARB":
          PRINT D$;"OPEN VARB": PRINT D$;"WRITE VARB"
0650 PRINT BD;",";C4;",";C2;",";C3;",";TH;",";TT;",";TA;",";TR
0660 PRINT D$;"CLOSE VARB"
0670 PRINT D$;"OPEN DATA2,D1": PRINT D$;"DELETE DATA2":
          PRINT D$;"OPEN DATA2": PRINT D$;"WRITE DATA2"
0680 FOR I = 1 TO 11: PRINT T(I);",";A(I): NEXT I
0690 PRINT D$;"CLOSE DATA2"
0700 INPUT A(12)
0710 PRINT D$;"OPEN DATA1,D1": PRINT D$;"DELETE DATA1":
          PRINT D$;"OPEN DATA1": PRINT D$;"WRITE DATA1"
0720 PRINT T$: PRINT A(12)
0730 PRINT D$;"CLOSE DATA1"
0740 PRINT D$;"OPEN DATA,D2": PRINT D$;"DELETE DATA":
          PRINT D$;"OPEN DATA": PRINT D$;"WRITE DATA":
          PRINT D$;"CLOSE DATA"
0750 REM
0760 REM     RUN PREDICTION PROGRAM
0770 REM
0780 PRINT D$;"RUN PREDICTION,D1"
0790 END
```

```
BASIC
APPLESOFT BASIC                                              PAGE 1

0010 REM
0020 REM                  PREDICTION PROGRAM
0030 REM                  ------------------
0040 REM
0050 REM        THIS PROGRAM DETERMINES WHETHER NORMAL OR ABNORMAL WEATH
        ER
0060 REM        WILL OCCUR FOR THE NEXT 24 HOURS
0070 REM
0080 REM        FOR NORMAL WEATHER, CALCULATE THE AVERAGE TEMPERATURE AN
0090 REM        THE COEFFICIENT OF THE HISTORIC CURVE
0100 REM
0110 REM        FOR ABNORMAL WEATHER, TEMPERATURE WILL BE CHECKED TO DET
        ERMINE
0120 REM        WHETHER THE WEATHER HAS RETURNED TO NORMAL OR IT REMAINE
        D AS A
0130 REM        WEATHER FRONT
0140 REM
0150 DIM XG(12),YG(12),XB(12),YB(12),X(48),Y(48)
0160 OM = 0.261799392:D$ =  CHR$ (4)
0170 DEF  FN EA(W) = C1 + C2 *  SIN (OM * W + 3 * TH) + C3 *  SIN (2 *
      OM * W + TH)
0180 DEF  FN EB(W) = C4 + C2 *  SIN (OM * W + 3 * TH) + C3 *  SIN (2 *
      OM * W + TH)
0190 REM
0200 REM        READ IN WEATHER DATA AND STORE THEM IN DATA FILES
0210 REM
0220 PRINT D$;"OPEN VARB,D1": PRINT D$;"READ VARB":
      INPUT BD,C4,C2,C3,TH,XG(12),YG(12),TR: PRINT D$;"CLOSE VARB"
0230 PRINT D$;"OPEN DATA2": PRINT D$;"READ DATA2": FOR I = 1 TO 11:
      INPUT XG(I),YG(I): NEXT : PRINT D$;"CLOSE DATA2"
0240 PRINT D$;"OPEN DATA1": PRINT D$;"READ DATA1": INPUT T$:
      INPUT YG(12): PRINT D$;"CLOSE DATA1":
     XG(12) =  VAL ( MID$ (T$,7,2))
0250 NN =  VAL ( LEFT$ (T$,2)): RESTORE : FOR I = 1 TO NN:
      READ C1,C2,C3,TH: NEXT
0260 REM
0270 REM         CHECK WHETHER THE PAST 12 HOUR WEATHERS HAVE FOLLOWED
0280 REM         HISTORIC TREND
0290 REM
0300 IF ( VAL ( MID$ (T$,4,2)) <  = 7) THEN NN =  VAL ( LEFT$ (T$,2))
     - 1: IF (NN = 0) THEN NN = 12
0310 IF ( VAL ( MID$ (T$,4,2)) =  > 23) THEN NN =  VAL ( LEFT$ (T$,2))
     + 1: IF (NN = 13) THEN NN = 1
0320 RESTORE : IF (NN <  >  VAL ( LEFT$ (T$,2))) THEN  FOR I = 1 TO NN:
      READ T1,T2,T3,T4: NEXT :C1 = (C1 + T1) / 2:C2 = (C2 + T2) / 2:
     C3 = (C3 + T3) / 2:TH = (TH + T4) / 2
0330 SM = 0: FOR I = 1 TO 6:SM = SM + (YG(I) -  FN EA(XG(I))): NEXT :
     C4 = C1 + SM / 6
0340 SM = 0: FOR I = 7 TO 12:TP = (YG(I) -  FN EB(XG(I))):
     SM = SM + TP ^ 2: NEXT :TP =  SQR (SM / 5)
0350 IF (TP > 1.6) THEN  GOTO 560
0360 REM
0370 REM                NORMAL WEATHER ROUTINE
0380 REM                ----------------------
0390 REM       CALCULATE THE AVERAGE TEMPERATURE FOR THE PAST 12 HOUR A
     ND
0400 REM       THE HISTORIC COEFFICIENT
0410 REM
0420 SM = 0: FOR I = 1 TO 12:SM = SM + (YG(I) -  FN EA(XG(I))): NEXT :
     C4 = C1 + SM / 12
0430 IF ((Y(7) -  FN EB(X(7))) < 1.5) THEN  FOR I = 1 TO 6:
```

```
          XB(I) = XB(I + 1):YB(I) = YB(I + 1): NEXT
0440 FOR I = 7 TO 11:XB(I) = XB(I + 1):YB(I) = YB(I + 1): NEXT
0450 PRINT D$;"OPEN DATA2": PRINT D$;"DELETE DATA2":
          PRINT D$;"OPEN DATA2": PRINT D$;"WRITE DATA2": FOR I = 1 TO 11:
          PRINT XB(I);",";YB(I): NEXT : PRINT D$;"CLOSE DATA2"
0460 PRINT D$;"OPEN VARB,D1": PRINT D$;"DELETE VARB":
          PRINT D$;"OPEN VARB": PRINT D$;"WRITE VARB":
          PRINT BD;",";C4;",";C2;",";C3;",";TH;",";XB(12);",";YB(12);",";
          TR: PRINT D$;"CLOSE VARB"
0470 REM
0480 REM     RUN NORMAL CONTROL PROGRAM
0490 REM
0500 PRINT D$;"RUN NORCONTROL,D1": REM     NORMAL DAY OPERATION
0510 REM
0520 REM                    ABNORMAL WEATHER
0530 REM                    ----------------
0540 REM       CHECK IF THE WEATHER HAS RETURNED TO NORMAL
0550 REM
0560 IF (BD <  > 0) THEN  PRINT D$;"OPEN DATAB": PRINT D$;"READ DATAB":
          FOR I = 1 TO BD: INPUT XB(I),YB(I): NEXT : PRINT D$"CLOSE DATAB
0570 IF (BD = 0) THEN  FOR I = 7 TO 11:XB(I - 6) = XB(I):
          YB(I - 6) = YB(I): NEXT :BD = 5
0580 IF (BD < 12) THEN SM = 0: FOR I = 1 TO BD:
          SM = SM + (YB(I) -  FN EA(XB(I))): NEXT :C4 = C1 + SM / BD
0590 IF (BD = 12) THEN SM = 0: FOR I = 1 TO 12:
          SM = SM + (YB(I) -  FN EA(XB(I))): NEXT :C4 = C1 + SM / 12:
          SM = 0: FOR I = 1 TO 12:TP = YB(I) -  FN EB(XB(I)):
          SM = SM + TP ^ 2: NEXT :TP =  SQR (SM / 11)
0600 IF (BD = 12 AND TP < 0.16) THEN  FOR I = 1 TO 6:XB(I) = XB(I):
          YB(I) = YB(I): NEXT : GOTO 300
0610 IF (BD = 12 AND TP > 0.16) THEN  FOR I = 1 TO 11:
          XB(I) = XB(I + 1):YB(I) = YB(I + 1): NEXT :BD = 11
0620 BD = BD + 1:XB(BD) = XB(12):YB(BD) = YB(12)
0630 REM
0640 REM     STORE ALL THE COEFFICIENTS IN DATA FILES
0650 REM
0660 PRINT D$;"OPEN DATAB": PRINT D$;"DELETE DATAB":
          PRINT D$;"OPEN DATAB": PRINT D$;"WRITE DATAB": FOR I = 1 TO BD:
          PRINT XB(I);",";YB(I): NEXT : PRINT D$"CLOSE DATAB"
0670 PRINT D$;"OPEN VARB,D1": PRINT D$;"DELETE VARB":
          PRINT D$;"OPEN VARB": PRINT D$;"WRITE VARB":
          PRINT BD;",";C4;",";C2;",";C3;",";TH;",";XB(12);",";YB(12);",";
          TR: PRINT D$;"CLOSE VARB"
0680 TZ = 0:TI = 0
0690 PRINT D$;"OPEN CONTROL,D1": PRINT D$;"DELETE CONTROL":
          PRINT D$;"OPEN CONTROL": PRINT D$;"WRITE CONTROL":
          PRINT TZ;",";TI: PRINT D$;"CLOSE CONTROL"
0700 REM
0710 REM       RUN ABNORMAL CONTROL PROGRAM
0720 REM
0730 PRINT D$;"RUN ABCONTROL,D1"
0740 REM
0750 REM       ****** DATA BLOCK ******
0760 REM
0770 DATA   3.375,2.7965,0.84673,1.1963,4.3958,3.9776,1.0081,1.1910,4.
          9625,4.4616,.90124,1.2429
0780 DATA  6.5833,5.9201,.67013,1.2640,8.3333,7.4836,.55840,1.2668,7.9
          375,7.1147,.58829,1.2951
0790 DATA 7.7292,7.2255,.70749,1.2798,8.1458,7.6278,1.0580,1.3085,6.42
          92,6.5738,1.1554,1.2958
0800 DATA  5.5833,5.2327,1.4642,1.2975,2.9917,2.9089,.94649,1.2820,2.2
```

167,1.9793,.71858.1.2422

```
BASIC
APPLESOFT BASIC                                                PAGE 1

0010 REM                  NORMAL CONTROL PROGRAM
0020 REM                  ----------------------
0030 REM       THIS PROGROM PERFORMS THE OPERATIONS FOR A NORMAL DAY
0040 REM       IT DETERMINES WHETHER ADVANCE HEATING OR ADVANCE COOLING
0050 REM       IS REQUIRED
0060 REM       IT DETERMINES WHETHER SUCH OPERATION IS POSSIBLE
0070 REM
0080 DEF  FN ASI(W) =  ATN (W /  SQR (1 - W * W)):
        DEF  FN ACO(W) =  -  ATN (W /  SQR (1 - W * W)) + 1.5708:
        DEF  FN EOT(W) = 0.1236 *  SIN (W) - 0.0043 *  COS (W) + 0.1538
       *  SIN (2 * W) + 0.0608 *  COS (2 * W)
0090 DEF  FN EA(W) = A(2) + A(3) *  SIN (OM(1) * W + 3 * A(5)) + A(4)
       *  SIN (2 * OM(1) * W + A(5))
0100 DIM A(20),OM(2),SM(2),SO(24),SQ(24),TA(24),TP(24),TR(24),TT(24),T
       M(24):D$ =  CHR$ (4):PI = 3.1415927
0110 PRINT D$;"OPEN VARB,D1": PRINT D$;"READ VARB":
        INPUT BD,A(2),A(3),A(4),A(5),TT(0),TA(0),TR(0):
        PRINT D$;"CLOSE VARB"
0120 BU =  - 3:BL =  - 10:CU = 24:CL = 18:CM = 21:CC = 0.055:R1 = 15:
       R2 = 210:RC = 13:OM(1) = 0.261799392:OM(2) = 1:SU = 0
0130 FOR I = 1 TO 24:TT(I) = TT(0) + I:SO(I) = 0.15:
        IF (TT(I) > 23) THEN TT(I) = TT(I) - 24
0140 IF (TT(I) > 6 OR TT(I) < 18) THEN SO(I) = 0.15
0150 NEXT I:SO(0) = 0.15:TM(0) = 2
0160 FOR I = 1 TO 24:SQ(I) = SO(I): NEXT I
0170 FOR I = 1 TO 24:TA(I) =  FN EA(TT(I)):TM(I) = 2:
        IF (TT(I) >  = 7 AND TT(I) < 18) THEN TM(I) = 2
0180 NEXT : GOSUB 800
0190 PRINT D$;"PR#1": FOR I = 1 TO 24: PRINT TT(I),TR(I),TA(I): NEXT I:
        PRINT D$;"PR#"
0200 FOR II = 1 TO 24
0210 IF (TR(II) > CU) GOTO 250
0220 IF (TR(II) < CL) GOTO 280
0230 NEXT II
0240 GOTO 700
0250 FOR JJ = II TO 24
0260 IF (TR(JJ) < CU) THEN  GOTO 440
0270 NEXT JJ: IF (JJ >  = 24) THEN JJ = 24: GOTO 440
0280 FOR JJ = II TO 24
0290 IF (TR(JJ) > CL) THEN  GOTO 590
0300 NEXT JJ: IF (JJ >  = 24) THEN JJ = 24: GOTO 590
0310 REM       SUBROUTINE :
0320 REM       ------------
0330 REM       THIS SUBROUTINE DETERMINES THE FOLLOWINGS:
0340 REM         SUNRISE AND SUNSET TIME
0350 REM         SOLAR TIME TO LOCAL TIME
0360 REM         INCIDENT ANGLE
0370 REM
0380 DIM AD(12): FOR I = 1 TO 12: READ AD(I): NEXT :
        DATA   31,28,31,30,31,30,31,31,30,31,30,31:LA = 0.793543
0390 N = 0:J =  VAL ( LEFT$ (T$,2)) - 1:
        IF (J <  > 0) THEN  FOR I = 1 TO J:N = N + AD(I): NEXT
0400 N = N +  VAL ( MID$ (T$,4,2)):
       DE = 0.39795 *  COS (0.0172025 * (N - 173)):DE =  FN ASI(DE)
0410 SR =  FN ACO( -  TAN (LA) *  TAN (DE)):SS = 12 + SR * 12 / PI:
       SR = 12 - SR * 12 / PI
0420 W = (N - 1) * 0.0172028:ET =  FN EOT(W):SR = SR + ET:SS = SS + ET:
       SR =  INT (SR):SS =  INT (SS):
       IC =  FN ACO( -  SIN (DE) *  COS (LA)): RETURN
0430 REM
0440 REM      THIS ROUTINE CALCULATES THE AMOUNT OF ADVANCE COOLING NEE
```

```
              DED
0450 REM      IT DETERMINES THE POSSIBLITY FOR ADVANCE COOLING AND THE
0460 REM      TIME IT WILL BR REQUIRED
0470 REM
0480 SM(1) = 0: FOR I = II TO JJ:
              IF (TR(I) > CU) THEN SM(1) = SM(1) + (TR(I) - CU) / R2
0490 NEXT
0500 VO = 0.02:SM(2) = 0: FOR TI = 1 TO II STEP 0.5:I =  INT (TI):
             TP(1) =  FN EA(TI + TT(0)):
              IF (TP(1) < TR(I)) THEN SM(2) = SM(2) + 0.5 * 1.2 * VO * (TR(I)
             - TP(1))
0510 IF (SM(2) >  = SM(1)) GOTO 530
0520 NEXT TI:TZ = 1:TI = 60: GOTO 1290
0530 FOR I = 1 TO 24:SO(I) = SQ(I): NEXT : FOR I = 1 TO TI STEP 0.5:
             J =  INT (I):TP(1) =  FN EA(I):
              IF (TP(1) < TR(J)) THEN SO(J) = SO(J) - 0.5 * 1.20 * VO * (TR(I
             ) - TP(1)): NEXT
0540 GOSUB 840
0550 FOR I = 1 TO JJ: IF (TR(I) < CL) THEN TI = TI - 0.5: GOTO 530
0560 NEXT : IF (TI < 1) THEN TI = TI + 60
0570 IF (TI >  = 1) THEN TI = 60
0580 TZ = 1: GOTO 1230
0590 REM
0600 REM      THIS ROUTINE CALCULATES THE AMOUNT OF ADVANCE HEATING NEE
             DED
0610 REM      IT DETERMINES THE POSSIBILITY OF HAVING ADVANCE HEATING
0620 REM      IT DETERMINES THE TIME FOR ADVANCE HEATING
0630 REM
0640 SM(1) = 0: FOR I = II TO JJ:
             IF (TR(I) < CL) THEN SM(1) = SM(1) + (TR(I) - CL) / R2
0650 NEXT
0660 FOR I = 1 TO 24:SO(I) = SQ(I) + SV: NEXT
0670 GOSUB 840
0680 FOR I = 1 TO JJ: IF (TR(I) > CU) THEN TZ = 0: GOTO 1230
0690 NEXT :TZ = 2: GOTO 1270
0700 REM
0710 REM      THIS ROUTINE CHECKS CHECKS IF THE ROOM TEMPERATURE CAN
0720 REM      REMAIN IN THE MIDDLE OF THE COMFORT ZONE
0730 REM
0740 SM(1) = 0: FOR I = 1 TO 24:SM(1) = SM(1) + (TR(I) - CM) ^ 2: NEXT
0750 IF (TR(0) = CM) THEN TZ = 0: GOTO 1290
0760 IF (TR(0) < CM) THEN  GOTO 1310
0770 IF (TR(0) > TA(0)) THEN  GOTO 1310
0780 VO = .02: FOR I = 1 TO 24:SO(I) = SQ(I): NEXT :
             SO(1) = SO(1) - 0.5 * 1.2 * VO * (TR(1) - TA): GOSUB 1050:
              FOR I = 1 TO 24: IF (TR(I) < CL OR TR(I) > CU) THEN  GOTO 1310
0790 TZ = 1: GOTO 1230
```

```
0800 REM
0810 REM      THIS ROUTINE CALCULATES THE ROOM TEMPERATURE ACCORDING TO
0820 REM      ROOM STORAGE
0830 REM
0840 A(6) =  SQR ((RC * CC * OM(2)) ^ 2 + 1)
0850 A(7) = 1 / ((RS + R2 + RC) * CC)
0860 A(8) =  ATN (RC * CC * OM(2))
0870 A(9) =  ATN (OM(2) / A(7))
0880 A(10) =  ATN (A(7) / (OM(1)))
0890 A(11) =  ATN (A(7) / (2 * OM(1)))
0900 A(12) = A(7) * SU * A(6) /  SQR (A(7) ^ 2 + OM(2) ^ 2)
0910 A(13) = OM(1) * A(7) * CC * A(3) /  SQR (A(7) ^ 2 + (OM(1)) ^ 2)
0920 A(14) = 2 * OM(1) * A(7) * CC * A(4) /  SQR (A(7) ^ 2 + (2 * OM(1
       )) ^ 2)
0930 FOR I = 1 TO 24
0940 IF (TM(I - 1) = 0) THEN TP(1) = A(12) *  SIN (OM(2) * TT(I - 1) -
       SR) + A(8) - A(9)):
       TP(2) = A(13) *  SIN (2 * OM(1) * TT(I - 1) + A(10) + 3 * A(5))
       + A(14) *  SIN (4 * OM(1) * TT(I - 1) + A(11) + A(5))
0945 IF (TM(I - 1) = 0) THEN A(1) = (TR(I - 1) - TA(I - 1)) / R2 - TP(
       1) + TP(2)
0950 IF (TM(I - 1) = 2 OR TM(I - 1) = 3) THEN TP(1) = A(13) *  SIN (OM
       (1) * TT(I - 1) + A(10) + 3 * A(5)) + A(14) *  SIN (2 * OM(1) *
       TT(I - 1) + A(11) + A(5))
0955 IF (TM(I - 1) = 2 OR TM(I - 1) = 3) THEN A(1) = ((TR(I - 1) - TA(
       I - 1)) / R2 + TP(1) - SO(I - 1)) *  EXP (A(7) * TT(I - 1))
0960 REM
0970 REM      RECALCULATE THE CAPACITOR TERM FOR DIFFERENT MODE
0980 REM
0990 IF (TT(I) > 0) THEN A(1) = A(1) *  EXP ( - A(7) * 24)
1000 IF (TM(I) = 1 AND TM(I - 1) = 1) THEN  GOSUB 1110
1010 IF (TM(I) = 1 AND TM(I - 1) = 2) THEN  GOSUB 1170
1020 IF (TM(I) = 1 AND TM(I - 1) = 3) THEN  GOSUB 1170
1030 IF (TM(I) = 2 AND TM(I - 1) = 1) THEN  GOSUB 1100
1040 IF (TM(I) = 2 AND TM(I - 1) = 2) THEN  GOSUB 1190
1050 IF (TM(I) = 2 AND TM(I - 1) = 3) THEN  GOSUB 1180
1060 IF (TM(I) = 3 AND TM(I - 1) = 1) THEN  GOSUB 1100
1070 IF (TM(I) = 3 AND TM(I - 1) = 2) THEN  GOSUB 1180
1080 IF (TM(I) = 3 AND TM(I - 1) = 3) THEN  GOSUB 1190
1090 NEXT : RETURN
1100 A(1) = A(1) + A(11) *  SIN (OM(2) * (TT(I) - SR) + A(8) - A(9))
1110 A(1) = A(1) *  EXP ( - A(7) * (TT(I - 1) - TT(I))) + SO(I - 1) -
       SO(I)
1120 TP(1) = A(1) *  EXP ( - A(7))
1130 TP(2) = A(12) *  SIN (OM(2) * (TT(I) - SR) + A(8) - A(9))
1140 TP(3) = A(13) *  SIN (OM(1) * TT(I) + A(10) + 3 * A(5))
1150 TP(4) = A(14) *  SIN (2 * OM(1) * TT(I) + A(11) + A(5))
1160 TP(5) = TP(1) + TP(2) - TP(3) - TP(4):TP(5) = SO(I) + TP(5):
       TR(I) = R2 * TP(5) + TA(I): RETURN
1170 A(1) = A(1) - A(11) *  SIN (OM(2) * (TT(I) - SR) + A(8) - A(9))
1180 A(1) = A(1) *  EXP ( - A(7) * (TT(I - 1) - TT(I))) + SO(I - 1) -
       SO(I)
1190 TP(1) = A(1) *  EXP ( - A(7) * TT(I))
1200 TP(2) = A(13) *  SIN (OM(1) * TT(I) + A(10) + 3 * A(5))
1210 TP(3) = A(14) *  SIN (2 * OM(1) * TT(I) + A(11) + A(5))
1220 TP(4) = TP(1) - TP(2) - TP(3):TP(4) = SO(I) + TP(4):
       TR(I) = R2 * TP(4) + TA(I): RETURN
1230 REM
1240 REM      THIS ROUTINE SENDS MESSAGE TO THE CONTROL SYSTEM
1250 REM
1260 IF (TR(0) > CL AND TR(0) < CU) THEN  IF (TR(0) > TA(0)) THEN TZ =
```

```
          1: GOTO 1290
1270 IF (TR(0) > CL AND TR(0) < CU) THEN  IF (TR(0) < TA(0)) THEN TZ =
          2: GOTO 1290
1280 TZ = 0
1290 FOR J = 1 TO 5: POKE 49243,0: FOR K = 1 TO 140: NEXT K:
          POKE 49242,0: FOR K = 1 TO 100: NEXT K: NEXT J
1300 IF (TZ = 0) THEN  GOTO 1340
1310 FOR I = 1 TO TZ: FOR J = 1 TO 5: POKE 49245,0: FOR K = 1 TO 400:
          NEXT K: POKE 49244,0: FOR K = 1 TO 200: NEXT K: NEXT J
1320 FOR J = 1 TO 13: POKE 49241,0: FOR K = 1 TO 800: NEXT K:
          POKE 49240,0: FOR K = 1 TO 500: NEXT K: PRINT J: NEXT J
1330 NEXT I
1340 PRINT D$;"IN#4": PRINT D$;"PR#4": INPUT T$: PRINT D$;"IN#0":
          PRINT D$;"PR#0"
1350 PRINT D$;"APPEND OPER,D2": PRINT D$;"WRITE OPER": PRINT T$:
          PRINT TZ: PRINT D$;"CLOSE OPER"
1360 PRINT D$;"OPEN CONTROL,D1": PRINT D$;"DELETE CONTROL":
          PRINT D$;"OPEN CONTROL": PRINT D$;"WRITE CONTROL":
          PRINT TZ;",";TI: PRINT D$;"CLOSE CONTROL"
1370 REM
1380 REM    RUN TIME CONTROL PROGRAM
1390 PRINT D$;"RUN TIMEC"
```

BASIC
APPLESOFT BASIC PAGE 1

```
0010 REM
0020 REM              ABNORMAL CONTROL PROGRAM
0030 REM              ------------------------
0040 REM        THIS PROGRAM ACTIVATES THE NECESSARY DEVICES WHICH CONTR
         OL
0050 REM        THE ROOM TEMPERATURE WITHIN THE MIDDLE OF THE COMFORT ZO
         NE.
0060 REM
0070 DIM A(20),OM(2),SM(2),SO(24),SQ(24),TA(24),TP(24),TR(24),TT(24),T
         M(24):D$ =  CHR$ (4):PI = 3.1415927
0080 PRINT D$;"OPEN VARB.D1": PRINT D$;"READ VARB":
          INPUT BD,A(2),A(3),A(4),A(5),TT(0),TA(0),TR(0):
          PRINT D$;"CLOSE VARB"
0090 BU =  - 3:BL =  - 10:CU = 24:CL = 18:CM = 21:CC = 0.055:R1 = 15:
         R2 = 210:RC = 13:OM(1) = 0.261799392:OM(2) = 1:SU = 0
0100 REM
0110 REM     CHECK ROOM TEMPERATURE
0120 REM     STORE THE CONTROL MODE INTO A FILE
0130 REM
0140 IF (TR(0) > CM) THEN  IF (TR(0) > TA(0)) THEN TZ = 1: GOTO 170
0150 IF (TR(0) < CM) THEN TZ = 0: GOTO 170
0160 TZ = 0
0170 FOR J = 1 TO 5: POKE 49243,0: FOR K = 1 TO 140: NEXT K:
          POKE 49242,0: FOR K = 1 TO 100: NEXT K: NEXT J
0180 IF (TZ = 0) THEN  GOTO 220
0190 FOR I = 1 TO TZ: FOR J = 1 TO 5: POKE 49245,0: FOR K = 1 TO 400:
          NEXT K: POKE 49244,0: FOR K = 1 TO 200: NEXT K: NEXT J
0200 FOR J = 1 TO 13: POKE 49241,0: FOR K = 1 TO 800: NEXT K:
          POKE 49240,0: FOR K = 1 TO 500: NEXT K: PRINT J: NEXT J
0210 NEXT I
0220 PRINT D$;"IN#4": PRINT D$;"PR#4": INPUT T$: PRINT D$;"IN#0":
          PRINT D$;"PR#0"
0230 TZ = 4
0240 PRINT D$;"APPEND OPER.D2": PRINT D$;"WRITE OPER": PRINT T$:
          PRINT TZ: PRINT D$;"CLOSE OPER"
0250 PRINT D$;"OPEN CONTROL.D1": PRINT D$;"DELETE CONTROL":
          PRINT D$;"OPEN CONTROL": PRINT D$;"WRITE CONTROL":
          PRINT TZ;",";TI: PRINT D$;"CLOSE CONTROL"
0260 REM
0270 REM  RUN TIME CONTROL PROGRAM
0280 REM
0290 PRINT D$;"RUN TIMEC"
```

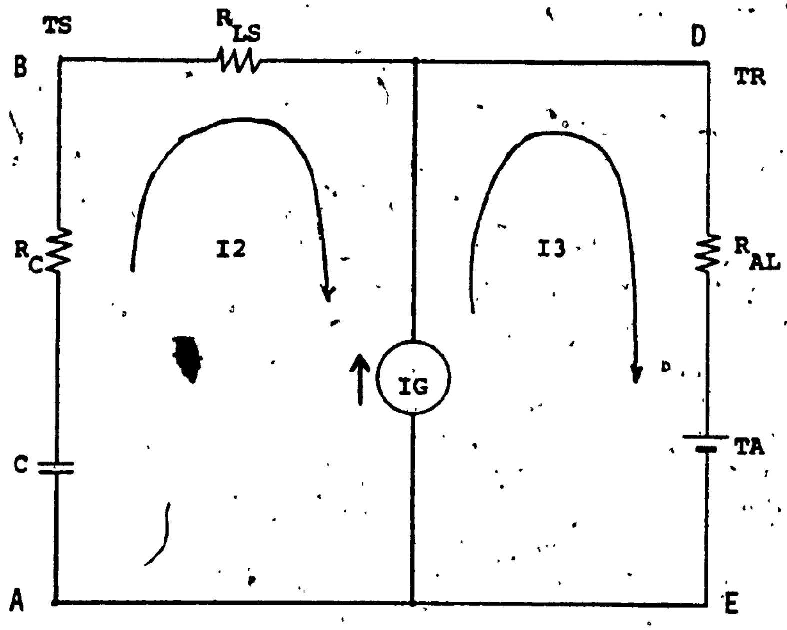
```
BASIC
APPLESOFT.BASIC                                         PAGE 1

0010 REM
0020 REM                  TIME CONTROL PROGRAM
0030 REM                  --------------------
0040 REM
0050 REM       THIS PROGRAMS CONTROLS THE OPERATION TIME AND
0060 REM       STORE THE WEATHERS IN A DATA FILE
0070 REM
0080 CLEAR :ZZ = 1
0090 D$ =  CHR$ (4): DIM TP(15),AD(12): FOR I = 1 TO 12: READ AD(I):
          NEXT : DATA        31,28,31,30,31,30,31,31,30,31,30,31:NC = 9
0100 PRINT D$;"BRUN AA/DD,D1"
0110 PRINT D$;"OPEN DATA1,D1": PRINT D$;"READ DATA1": INPUT T$:
          INPUT CC: PRINT D$;"CLOSE DATA1"
0120 PRINT D$;"OPEN CONTROL": PRINT D$;"READ CONTROL": INPUT N3,SC:
          PRINT D$;"CLOSE CONTROL"
0130 REM
0140 REM       CHECK FOR VALID TIME
0150 REM       READ IN WEATHER DATA FROM DATA ACQUISITION
0160 REM
0170 Z = 1
0180 SC = SC * 60
0190 GOSUB 840:M3 = M:H3 = H:D3 = D:ME = MT:N4 = 10
0200 SC = 900: GOSUB 840: HOME
0210 VTAB (5): HTAB (2): PRINT "TIME       :"
0220 PRINT D$;"IN#4": PRINT D$;"PR#4": INPUT " ";T1$: PRINT D$;"IN#0":
          PRINT D$;"PR#0": VTAB (5): HTAB (17): PRINT  LEFT$ (T1$,14)
0230 M1 =  VAL ( MID$ (T1$,1,2)):D1 =  VAL ( MID$ (T1$,4,2)):
        H1 =  VAL ( MID$ (T1$,7,2)):M2 =  VAL ( MID$ (T1$,10,2)):
        S1 =  VAL ( MID$ (T1$,13,2))
0240 GOSUB 670
0250 REM
0260 REM       CHECK WHETHER INPUT DATA IS REASONABLE
0270 REM
0280 IF (TP(0) - TP(6) >  = 2) THEN  GOTO 220
0290 IF (M2 = 0 OR M2 = 5 OR M2 = 10 OR M2 = 15 OR M2 = 20 OR M2 = 25
        OR M2 = 30) THEN  GOSUB 710: GOSUB 910
0300 IF (N3 <  > 0) THEN  IF (M2 >  = M3) THEN  IF (H1 >  = H3) THEN
        IF (D1 >  = D3) THEN  IF (M1 >  = ME) THEN  FOR J = 1 TO 5:
         POKE 49243,0: FOR K = 1 TO 140: NEXT K: POKE 49242,0:
         FOR K = 1 TO 100: NEXT K: NEXT J:N3 = 0
0310 REM
0320 REM       CHECK FOR VALID ROOM TEMPERATURE FOR PERSENT OPERATION M
        ODE
0330 REM
0340 IF (N3 = 4 AND TP(4) > 21) THEN N2 = 1: GOTO 490
0350 IF (N3 = 4 AND TP(4) < 19) THEN N2 = 0: GOTO 490
0360 IF (N2 = 2 AND TP(4) > 18.5) THEN N2 = 0: GOTO 490
0370 IF (N2 = 3 AND TP(4) < 23.5) THEN N2 = 0: GOTO 490
0380 IF (N3 = 0 AND TP(4) > 18 AND TP(4) < 24) THEN N2 = 0: GOTO 490
0390 IF (N3 = 0 AND TP(4) > 24 AND TP(4) > TP(0)) THEN N2 = 1: GOTO 49
0400 IF (N3 = 1 AND TP(4) < 17.5) THEN N2 = 2:N3 = 0: GOTO 490
0410 IF (N3 = 1 AND TP(4) <  = 18) THEN N2 = 0: GOTO 490
0420 IF (N3 = 1 AND TP(4) < TP(0)) THEN N2 = 0: GOTO 490
0430 IF (N3 = 1 AND TP(4) > 18 AND TP(4) > TP(0)) THEN N2 = 1: GOTO 49
0440 IF (N3 = 1 AND TP(4) < 24 AND TP(4) < TP(0)) THEN N2 = 0: GOTO 49
0450 IF (N3 = 2 AND TP(4) > 18) THEN N2 = 0:N3 = 0: GOTO 490
0460 IF (N3 = 3 AND TP(4) < 24) THEN N2 = 0: GOTO 490
0470 IF (TP(4) < 18) THEN N2 = 2: GOTO 490
0480 IF (TP(4) > 24) THEN N2 = 3: GOTO 490
0490 IF (N2 = 0) THEN  FOR J = 1 TO 5: POKE 49243,0: FOR K = 1 TO 140:
         NEXT K: POKE 49242,0: FOR K = 1 TO 100: NEXT K: NEXT J:
```

```
          GOSUB 890: GOTO 220
0500 REM
0510 REM      ACTIVATE CONTROL SYSTEM
0520 REM      DOUBLE CHECK THAT THE CORRECT FUNCTION  HAS BEEN ACTIVAT
        ED
0530 REM        0 = NO OPERATION
0540 REM        1 = FAN
0550 REM        2 = HEATER
0560 REM        3 = CHILLER
0570 REM
0580 IF (N2 <  > 0 AND  PDL (N2) = 0) THEN  GOTO 220
0590 REM
0600 REM      READ WEATHER DATA FROM DATA ACQUISITION
0610 REM
0620 FOR J = 1 TO 5: POKE 49243,0: FOR K = 1 TO 140: NEXT K:
          POKE 49242,0: FOR K = 1 TO 100: NEXT K: NEXT J
0630 FOR I = 1 TO N2: FOR J = 1 TO 5: POKE 49245,0: FOR K = 1 TO 400:
          NEXT K: POKE 49244,0: FOR K = 1 TO 200: NEXT K: NEXT J
0640 FOR J = 1 TO 13: POKE 49241,0: FOR K = 1 TO 800: NEXT K:
          POKE 49240,0: FOR K = 1 TO 500: NEXT K: NEXT J
0650 NEXT I
0660 GOSUB 890: GOTO 220
0670 POKE 49245,0: FOR K = 1 TO 800: NEXT K: POKE 49244,0:
          FOR K = 1 TO 500: NEXT K: FOR I = 0 TO NC - 1:
          FOR II = 1 TO 300: CALL 49664: NEXT II
0680 TP(I) = 0: FOR II = 3 TO 5:
        TP(I) = ( PEEK (49856 + II) - 176) / 10 ^ (II - 2) + TP(I):
          NEXT II:TP(I) = TP(I) + ( PEEK (49857) - 176):
        TP(I) = (TP(I) - 1.893) * 14.8
0690 POKE 49241,0: FOR K = 1 TO 1000: NEXT K: POKE 49240.0:
          FOR K = 1 TO 600: NEXT K: NEXT I: RETURN
0700 REM
0710 REM      STORE DATA IN COMMON DATA FILES.
0720 REM
0730 PRINT D$;"OPEN VARB,D1": PRINT D$;"READ VARB":
          INPUT BD,A(2),A(3),A(4),A(5),TT,TA,TR: PRINT D$;"CLOSE VARB"
0740 TT =  VAL ( MID$ (T1$,7,2)):TA = TP(0):TR = TP(4)
0750 PRINT D$;"OPEN VARB,D1": PRINT D$;"DELETE VARB":
          PRINT D$;"OPEN VARB": PRINT D$;"WRITE VARB"
0760 PRINT BD;",";A(2);",";A(3);",";A(4);",";A(5);",";TT;",";TA;",";TR:
          PRINT D$;"CLOSE VARB"
0770 REM
0780 REM      RUN PREDICTION PROGRAM
0790 REM
0800 PRINT D$;"RUN PREDICTION"
0810 REM
0820 REM      CHANGE INPUT TIME FROM CHARACTER TO NUMBER
0830 REM
0840 MT =  VAL ( MID$ (T$,1,2)):D =  VAL ( MID$ (T$,4,2)):
        H =  VAL ( MID$ (T$,7,2)):M =  VAL ( MID$ (T$,10,2)):
        S =  VAL ( MID$ (T$,13,2)):S = S + SC:M = M +  INT (S / 60)
0850 S = S -  INT (S / 60) * 60:H = H +  INT (M / 60):
        M = M -  INT (M / 60) * 60:D = D +  INT (H / 24):
        H = H -  INT (H / 24) * 24
0855 MT = MT +  INT (D / AD(MT)):D = D -  INT (D / AD(MT)) * AD(MT):
          IF (MT > 12) THEN MT = MT - 12
0860 RETURN
0870 REM      RECORD ANY SYSTEM THAT WAS TURN ON AND LATER ANALYSIS
0880 REM
0890 VTAB (21): PRINT N2: IF (N2 = N4) THEN  RETURN
0900 PRINT D$;"APPEND OPER,D2": PRINT D$;"WRITE OPER": PRINT T1$;
```

```
          PRINT N2: PRINT D$;"CLOSE OPER":N4 = N2: RETURN
0910 IF (ZZ <  > 3) THEN  FOR I = 1 TO NC - 1:SU(I) = SU(I) + TP(I):
          NEXT I:Z = Z + 1: RETURN
0920 FOR I = 1 TO NC - 1:TP(I) = SU(I) / 3:SU(I) = 0: NEXT I:Z = 1
0930 FOR I = 0 TO NC - 1: PRINT D$;"APPEND CHANO";I;",D2":
          PRINT D$;"WRITE CHANO";I
0940 PRINT  LEFT$ (T1$,14):TP$ =  STR$ (TP(I)): PRINT  LEFT$ (TP$,5)
0950 PRINT D$;"CLOSE CHANO";I: NEXT I
0960 PRINT
0970 FOR I = 0 TO NC - 1
0980 PRINT "   ";I;"  ";: PRINT TP(I);" DEG C"
0990 NEXT I: RETURN
```

APPENDIX F

Determination of C, R_C, R_{LS} and R_{AL} from four measurements of each of TA, TR and TS



At time t TA, TR & TS are known from experiment

From DE

$$\frac{TR - TA}{R_{AL}} = I3 \qquad (F.1)$$

and $$I3 - I2 = IG \qquad (F.2)$$

From eq. F.1 and Eq. F.2

$$I2 = \frac{TR - TA}{R_{AL}} - IG \qquad (F.3)$$

also I2 can be express as:

$$I2 = A * e^{-\alpha t} \qquad (F.4)$$

where:

$$\alpha = \frac{1}{(R_{AL}+R_{LS}+R_C)*C}$$

From eq. F.2 & eq. F.4

$$\frac{TR - TA}{R_{AL}} = A * e^{-\alpha t} + IG \qquad (F.5)$$

also from circuit

$$R_{LS} = \frac{TS - TR}{A*e^{-\alpha t}} \qquad (F.6)$$

From F.5 with 2 data points t_1, t_2

$$\frac{(TR_1 - TA_1) - IG * R_{AL}}{(TR_2 - TA_2) - IG * R_{AL}} = e^{-\alpha(t_1-t_2)} \qquad (F.7)$$

From F.5 with another 2 data points t_3, t_4

$$\frac{(TR_3 - TA_3) - IG * R_{AL}}{(TR_4 - TA_4) - IG * R_{AL}} = e^{-\alpha(t_3-t_4)} \qquad (F.8)$$

If the interval between two readings is constant

$$t_1 - t_2 = \text{constant} = 1 \text{ hr.}$$

and let $F(\alpha) = e^{-\alpha}$

From eq. F.7

$$F(\alpha) = \frac{(TR_1 - TA_1) - IG * R_{AL}}{(TR_2 - TA_2) - IG * R_{AL}} \qquad (F.9)$$

From eq. F.8

$$R_{AL} = \frac{[(TR_3 - TA_3) - F(\alpha)(TR_4 - TA_4)]}{IG * [1 - F(\alpha)]} \qquad (F.10)$$

from $F(\alpha)$

$$\alpha = -\frac{1}{\ln[F(\alpha)]} \qquad (F.11)$$

From eq. F.5

$$R_{LS} = \frac{TS - TR}{A*e^{-\alpha t}} \qquad (F.12)$$

and

$$R_C = \frac{(TS + \alpha * A*e^{-\alpha t})}{[(TR - TA)/R_{AL} - IG]} \qquad (F.13)$$

$$C = \frac{\alpha}{(R_{AL}+R_C+R_{LS})} \quad \text{(F.14)}$$