

THE DEVELOPMENT OF A
COMPUTER-AIDED BUILDING BIOCLIMATIC ANALYSIS MODEL
AND ITS APPLICATION TO
TO THE REGION OF FRESNO, CALIFORNIA

by

Victor H. Allison

A Master's Degree Project
Submitted in Partial Fulfillment
of the Requirements for the Degree
Master of Environmental Design

The University of Calgary
Calgary, Alberta
June 1986

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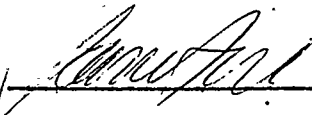
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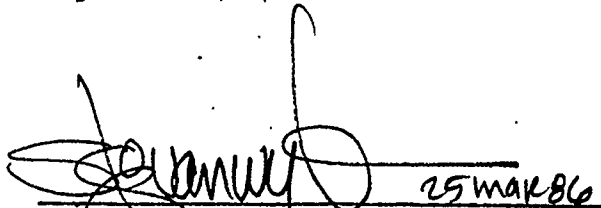
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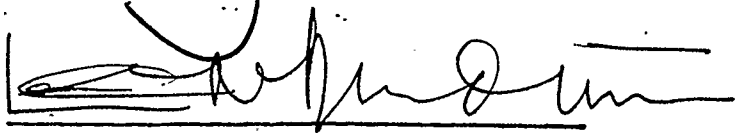
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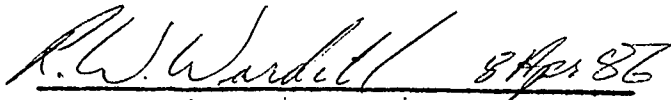
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ABSTRACT

THE DEVELOPMENT OF A COMPUTER-AIDED BUILDING BIOCLIMATIC ANALYSIS MODEL AND ITS APPLICATION TO THE REGION OF FRESNO, CALIFORNIA

by
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in the Faculty of Environmental Design
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Prof. James Love
Supervisor

The purpose of this study was the implementation of a series of computer programmes that an architect could use to develop a preliminary design concept for an energy-conscious building. Using a climate database as their input the computer programmes generate a series of graphs and charts that indicate which of a series of passive design strategies (such as promoting solar gain), are potentially useful in reducing a building's demands on purchased energy while ensuring an occupant's comfort. The graphs also assist the architect in determining whether the climate can, in fact, meet the various needs of the individual passive strategies.

An analysis spreadsheet was also implemented that determines the economic balance point between energy conserving features such as insulation levels and passive solar features like a trombe wall.

A method that an architect might employ to develop a preliminary design concept is demonstrated using the graphs and charts generated by the model for the climate of Fresno, California, and the results of that analysis are presented.

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I would like to thank Professor Jim Love of the Faculty of Environmental Design for his insightful criticisms and support of this project through its completion and for acting as the chairperson of my supervisory committee. I would also like to express my gratitude to Professor Lawrence Nkemdirim of the Department of Geography for his comments and criticisms as a member of my committee. Professor Skip Van Wyk of the College of Architecture and Environmental Design at Arizona State University deserves special mention for his work as an interim committee member and for his enthusiastic support of this work from its initial conception.

I would also like to thank the Student Awards Committee of the Faculty of Environmental Design, the Research Services Office of the Department of Graduate Studies and The Office of the Vice President (Academic) for their financial contributions towards this project.

I owe a special note of thanks to Sharon Hill for the loving support and understanding she proffered to me during all phases of this project. And finally, I would like like to express my gratitude to my father, Herbert Allison, for his continuous support of my endeavours.

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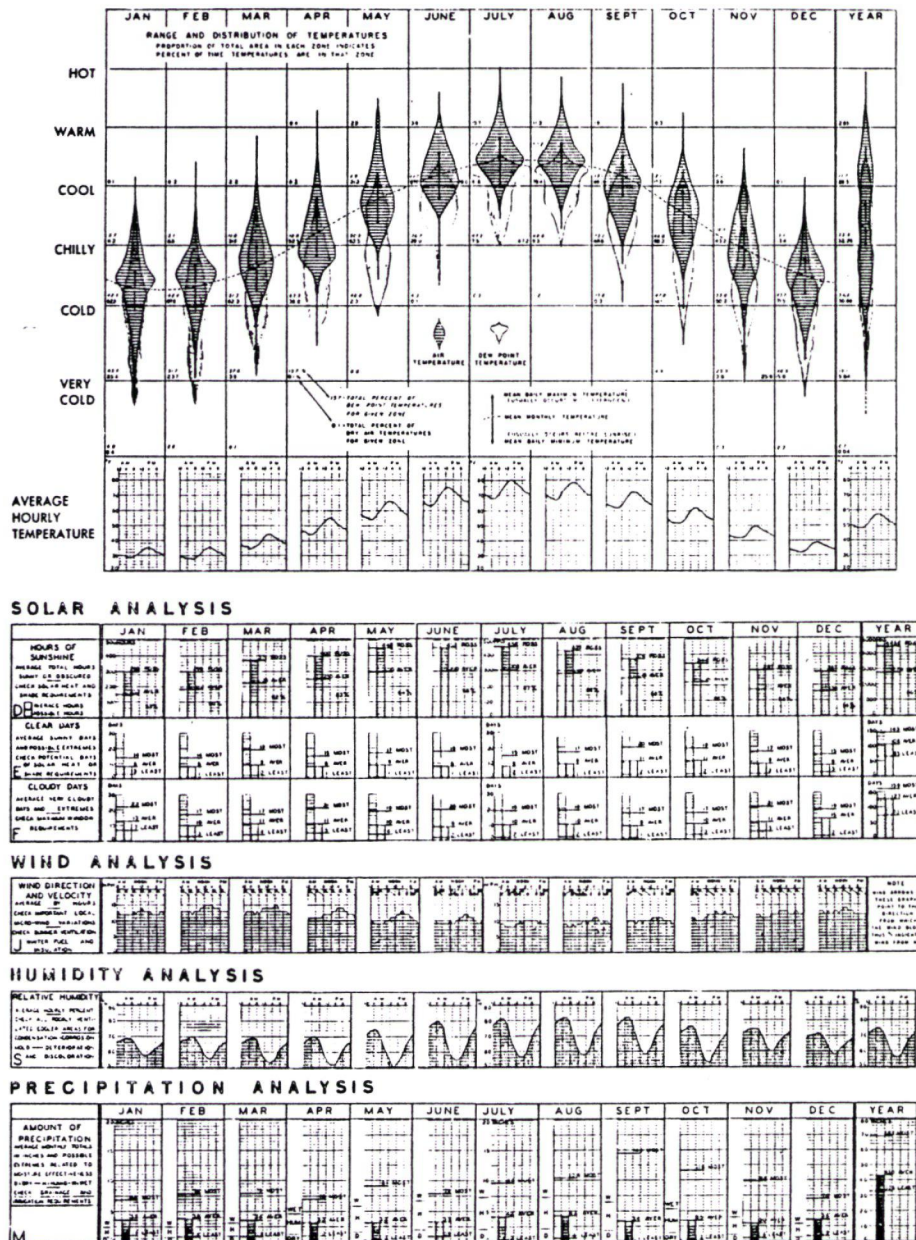
1. INTRODUCTION

1.1. PURPOSE OF THE STUDY

Climate analysis is a typical aspect of the pre-design research that is undertaken by architects who design energy conscious buildings. However, the traditional representations of climatic data do not provide the architect with any clues as to what to do with the data in order to apply it to a design.

A typical climatic evaluation for the New York - New Jersey area was presented in Olgyay (1963) and is reproduced in Figure 1.1. In the words of Olgyay: "Local weather data supplied by meteorological stations may give the architect information that will enable him to construct his own evaluation"[1]. Although the analysis presented was quite extensive, it still did not give the architect any real idea of how to 'construct his own evaluation' with the charts to apply them to a design.

The passive heating and cooling potentials of a building can be realized through its form, orientation, material selection and other architectural features. A design that relates a building's form and materials to its site and climate will result in the enhancement of its energy performance and reduce demand on non-renewable energy resources.



A Typical Climatic Evaluation

(Victor Olgyay with Aladar Olgyay, Design With Climate: Bioclimatic Approach to Architectural Regionalism. Copyright (c) 1963 by Princeton University Press. Reprinted by permission of Princeton University Press.)

Figure 1.1

The purpose of this study was the development, implementation and application of a series of graphic design tools and an analysis spreadsheet that can be used to design buildings that work with, rather than against, climate. As architects are generally more comfortable with graphic information than with tables of data, the end result of each tool is in the form of a graph or chart.

This type of climate analysis is advantageous as it provides the architect with easily interpreted information on what types of passive cooling and conserving strategies are useful in promoting the comfort of a building's occupants. It also indicates whether solar gain is advantageous or detrimental to the occupant's comfort. With this information the designer is then in a position to decide what types of heating, conserving or cooling features the design should use. This analysis would also prove highly valuable to an architect commissioned with a design in an area with unfamiliar climate.

The graphic analysis tools provide the architect with a clear monthly picture of the hourly trends in the climate of a selected location. The indicated hourly trends also facilitate the architect's understanding of the climate's effects on human comfort. More importantly, the analysis tools correlate the climate with a series of design strategies (such as promoting solar gain or ventilation) that can help to mitigate the heating or cooling loads that the climate imposes on the building. Some

of the tools provide the architect with information on whether the climate can in fact meet the needs of a specific strategy; for example, is there wind available during those times when the strategy of ventilation is indicated as viable for cooling.

The analysis spreadsheet is used to determine the economic balance between energy conserving features such as the insulation levels and passive solar features such as a trombe wall. The spreadsheet calculates the optimum insulation levels for various building components like the walls, ceiling and so forth. It also provides an indication of the heating energy used by the design as well as costs for the solar and conservation add-on features.

The spreadsheet is an interactive computer tool that allows the designer to quickly and easily compare the energy conserving and economic advantages of various passive design features and construction types.

1.2. SCOPE

This project is limited to a consideration of dry bulb temperature, dew point temperature, atmospheric pressure, direct insolation, total horizontal insolation, wind speed and wind direction as input parameters. The Typical Meteorological Year (TMY) climate database which is used as input for the model

contains other parameters such as sky cover, occurrences of rain and snow and number of hours of sunshine which could have been used to derive inputs for the tools. Even though the model is applicable to any location for which hourly weather data is available, it was the intention of this report to demonstrate the model's application to one selected site rather than present a series of analyzed sites. The climate of Fresno, California, was selected as it shows the applicability of the design tools to both under-heated and over-heated climates.

1.3. LIMITATIONS

1.3.1. Climate Database Requirements

The graphic design tools are limited to those locations for which hourly measures of dry bulb temperature, dew point temperature, atmospheric pressure, wind speed and wind direction are available. One of the tools uses hourly direct and total horizontal insolation as inputs which limits it to the 26 SOLMET stations unless this data is generated by a user-supplied model. See Section 3.1 for additional details on the climate database requirements.

The use of the spreadsheet is limited to those 219 American and Canadian locations for which load collector ratio and solar savings fraction tables have been tabulated in the Passive Solar

Design Handbook (Los Alamos Laboratories, 1984).

1.3.2. Building Types

The bioclimatic analysis is further limited to those building types whose energy requirements can be described as 'skin load dominated'. This class of buildings both gains and loses the majority of its thermal energy through its walls, glazing, roof, floor or basement and by infiltration or exfiltration. Thus excluded are buildings with large internal heat gains such as office complexes.

1.3.3. Microclimate Considerations

The microclimate of a building site can generally be expected to differ from the collection point of the climatic data, typically an airport or a weather station for a geographic region. This is especially true if the collection point is known to exist near a large body of water as this can alter both the dry bulb and wet bulb temperatures. It is unlikely that any temperature or pressure differences between the data collection site and a local building site would significantly affect the overall trends indicated by the model.

The wind analysis tool provides the architect with an accurate description of the winds at the climatic data collection site. However, as the existing winds are likely to be altered by a site's topography or surrounding structures, the designer should

interpret the output of the wind analysis tool with these facts in mind. As a detailed study of the winds at any building site is beyond the architect's normal role, the wind analysis tool is seen as a useful alternative to a microclimatic study of a specific site. Ideally, an architect would gather wind information from the building site but this is a very time consuming process. As wind direction is not as critical as wind speed or availability in ventilating strategies, the wind analysis tool still gives a good indication of the viability of ventilation as a cooling strategy.

1.3.4. Local Construction Cost Information

The spreadsheet requires the user to enter the local construction costs for various building components such as the walls, glazing and so forth. Thus, if the architect is designing for an unfamiliar area it is necessary to conduct some background research before using the spreadsheet tool.

1.3.5. Spreadsheet Algorithm Simplifications

In an effort to make the spreadsheet analysis simple enough for these rapid calculations the algorithms employed must use simplifications of the otherwise exceedingly complex heat transfer equations. It is the contention of the authors of the algorithms that they produce results in close agreement with calculations of a more rigorous nature[2]. Since simplified algorithms for dealing with passive cooling load calculations

have yet to be developed, the spreadsheet concerns itself only with heating loads.

1.3.6. Energy Cost Considerations

In order to simplify the analysis no attempt was made to incorporate local energy costs into the design guidelines produced in Chapter 7. This assumption does not effect the recommendations, as the energy costs would be constant in any given location. This fact allows the user to compare alternative buildings by a consideration of the energy use figures alone.

1.4. DEFINITION OF TERMS

The text of this report refers to several keywords. The definitions of these keywords as used in this text are as follows:

Bioclimatic Analysis - An evaluation of prevailing climatic conditions with respect to human comfort. "... is the starting point for any architectural design aiming at environmental climate balance"[3].

Building Load Coefficient (BLC) - A measure of the insulating quality of a building exclusive of the south facade and is equal to the Net Reference Load per degree of the difference between indoor and outdoor temperature per day[4].

Conservation Factor (CF) - A factor used to determine optimum conservation levels. See page 307, the Passive Solar Design Handbook (Los Alamos Laboratories, 1984) for its mathematical formulation.

Database - A collection of information existing on hard disk or on tape. It is most easily visualized as a matrix of data ordered into rows and columns. Specific databases referred to in the text are capitalized and proceeded/followed by an asterisk, e.g. *BCPDATA*.

Field - A 'column' of a database containing specific data. See Figure 3.2 where the first field of *CONV2.TMYFRE* contains the 'month' data.

File - A database stored on the computer's hard disk.

Hard disk - The computer's data storage area.

Load Collector Ratio (LCR) - The ratio of the Building Load Coefficient to the solar collection area[5].

Model - The Computer-Aided Building Bioclimatic Analysis Model.

Net Reference Load - The steady state heat loss from a building excluding the solar wall. The indoor temperature is assumed to be constant (normally 18 °C)[6].

Programme - Executable computer code. Specific programmes referred to in the text are capitalized, e.g. SOLPATH.

Record - A 'row' of a database containing one entry for each field.

Solar Savings - The energy savings due to the solar energy system relative to the energy requirements of a reference non-solar building that has an energy-neutral wall in place of the solar wall.

Solar Savings Fraction (SSF) - The difference in the auxiliary heat required with and without the solar energy system. The SSF is equal to 1.0 - the ratio of the auxiliary heat required by the solar building to the auxiliary heat required by the reference building[7].

Vapor Pressure - The partial pressure exerted by the variable quantity of water vapor present in the atmosphere.

Zone - A polygon of the Building Bioclimatic Chart (Figure 2.4) that defines a passive climate control strategy.

1.5. ORGANIZATION OF THE REPORT

The remainder of this report consists of seven major sections. Chapter Two provides an overview of previous research that was both instrumental in developing the initial concept for the computer models and refining them to their present state.

Chapter Three outlines the functions of each of the computer programmes that comprise the model and the databases that the model analyzes and/or produces. Chapter Three also deals with the workings of the spreadsheet.

Chapter Four addresses the question of the application of the output of the model to a design for the Fresno region. Although a detailed design of any structure is beyond the scope of this report, Chapter Four attempts to provide some insights into how the model might be applied in a real world situation.

Chapter Five presents a discussion of the application of the spreadsheet to a design for the Fresno region.

In Chapter Six, the models and their outputs are assessed with respect to their usefulness as design tools. Their limitations are reviewed in light of the findings of Chapters Four and Five.

Chapter Seven concludes with a summary of design guidelines for

the Fresno region based on the outputs of the models.

Suggestions for refinements and for further research are also presented.

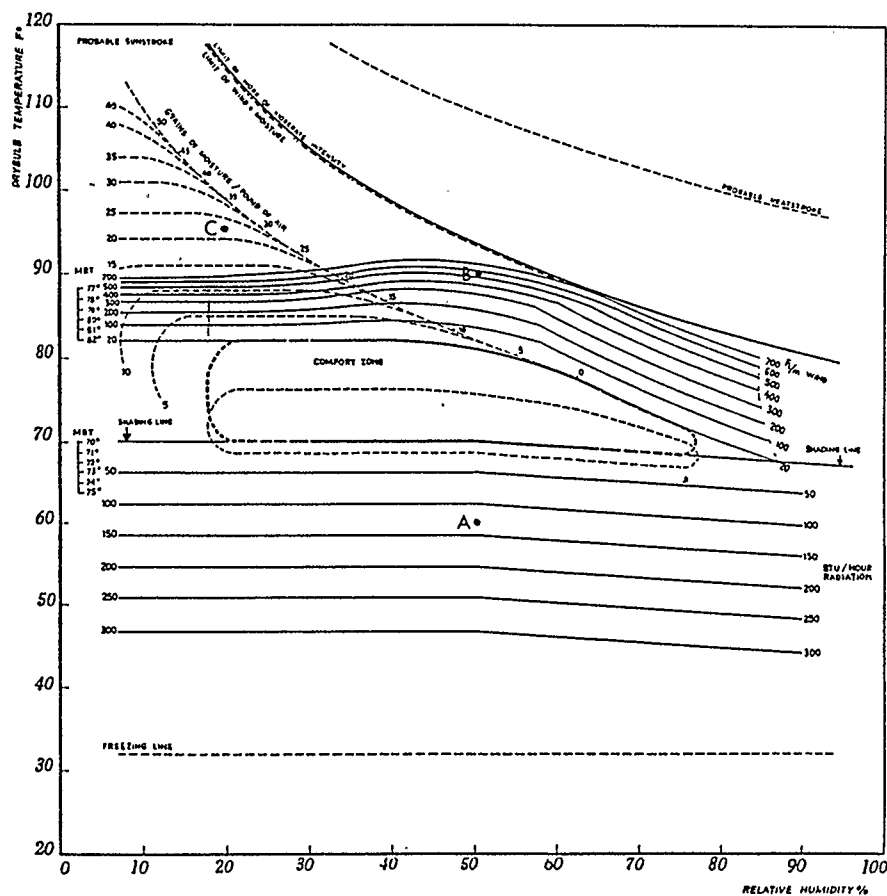
This report concludes with bibliographic information and appendices containing the complete outputs of the model, further discussions of the climate database and its modifications and the solar savings fraction.

2. PREVIOUS RESEARCH

2.1. BIOCLIMATIC ANALYSIS

The starting point of this research was a study of the work of Victor Olgyay that was performed at Princeton in the 1950's and published as Design With Climate (Olgyay, 1963). In his work Olgyay sought to quantify the relation of the climatic elements of air movement, vapor pressure, radiation and evaporation to human comfort. Olgyay produced the 'Bioclimatic Chart' (reproduced in Figure 2.1) which demonstrated the effects of the climatic elements on human comfort. Any position on the bioclimatic chart is described in terms of the temperature and relative humidity values which define the ordinate and the abscissa of the chart. Surrounding the 'Comfort Zone' in the center of the chart are a series of curves which indicate what type of corrective measure(s) are necessary to restore the feeling of comfort at any point outside the comfort zone. Hence, we see that at a temperature of 15 degrees (60 °F) and a relative humidity of 50 percent (Point A), 158 kilojoules per hour (150 BTU/hr) of radiation are required for comfort. At 32 degrees (90 °F) and 50 percent relative humidity a breeze of 2.5 to 3.0 metres per second (500 - 600 ft/min) is needed for comfort. (See Point B). At a temperature of 35 degrees (95 °F) and 20 percent

relative humidity a breeze alone is not sufficient for comfort as the air is too dry. (See Point C). At this condition comfort can be achieved by either a combination of evaporative cooling at 1.3 grams of moisture per kilogram of air (9 gr/lb) with a breeze of 3.5 metres per second (700 ft/min) or solely by evaporative cooling at 3.1 grams per kilogram (22 gr/lb).



The Bioclimatic Chart

(Victor Olgyay with Aladar Olgyay, Design With Climate: Bioclimatic Approach to Architectural Regionalism. Copyright (c) 1963 by Princeton University Press. Reprinted with permission of Princeton University Press.)

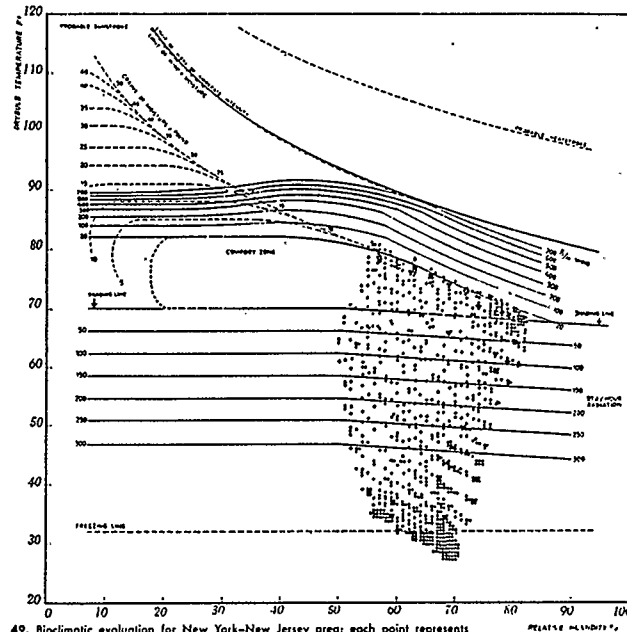
Figure 2.1

The usefulness of Olgyay's work is limited in that its definition of "comfort" applies only to a human without the benefits of a surrounding structure (other than a shading device). Olgyay states: "A trained eye by merely looking at the charts may detect and 'diagnose' the architectural requirements of a region"[8]. Unfortunately he gave little indication by what method the eye may be trained or how a 'trained eye' might reach a bioclimatic design. There is no apparent way of making the leap from comfort without a building to comfort within a building and so his model is of limited use from the standpoint of architectural design.

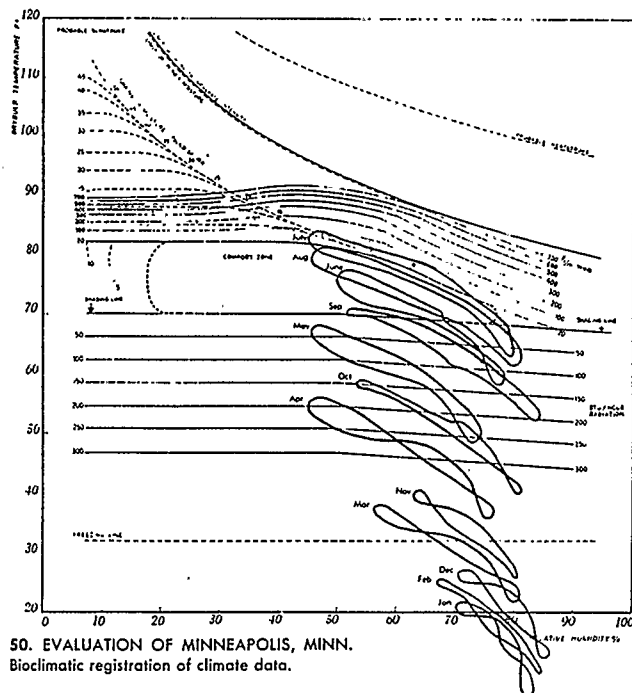
I developed a computer-aided bioclimatic analysis model in 1984 based on two figures from Olgyay (1963) which are reproduced in Figure 2.2. These figures depict the bioclimatic chart overlaid with hourly climatic data. An analysis based on the bioclimatic chart was not pursued because of its limited application to architectural design. However, it was this initial research project that paved the way to the model's present form.

2.2. CLIMATE BASED DESIGN

A method similar to that of Olgyay was proposed in Givoni (1969). Givoni's analysis differed in that it was based on the psychrometric chart (see Figure 2.3) and gave " ... the designer an accurate representation of the potential effect of the



49. Bioclimatic evaluation for New York-New Jersey area; each point represents hourly data over ten-day periods throughout the year.

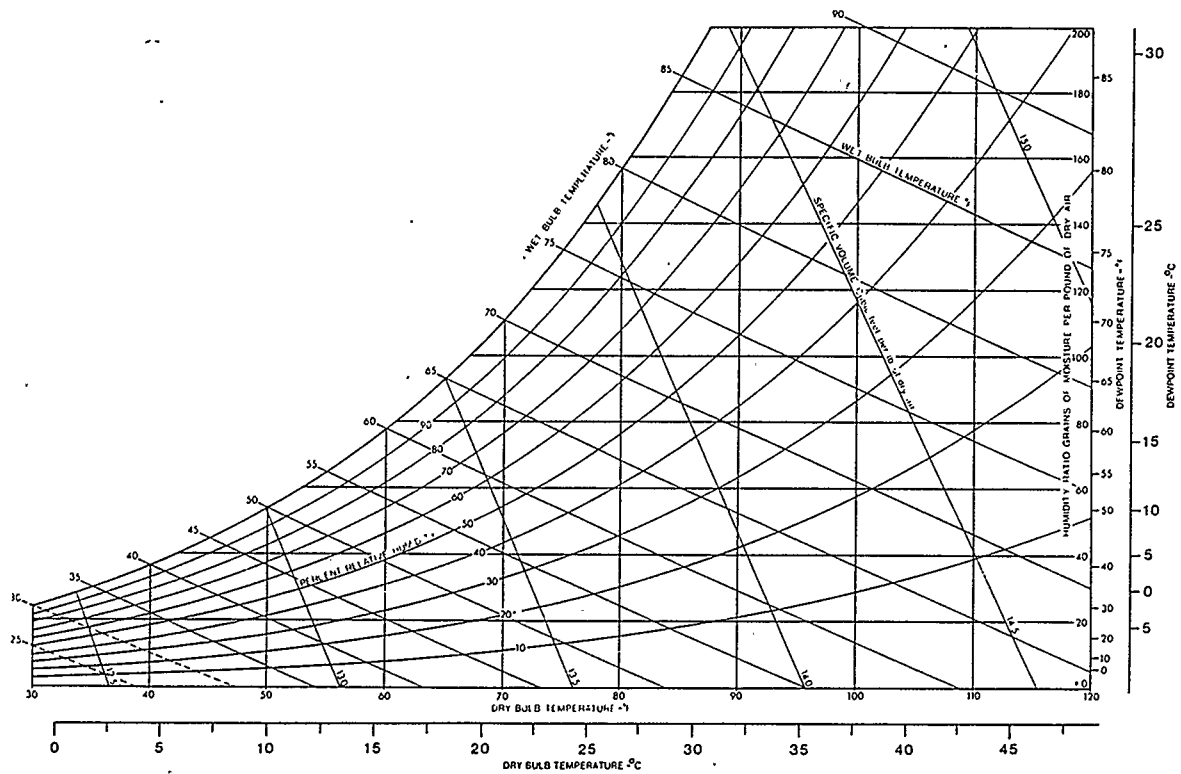


50. EVALUATION OF MINNEAPOLIS, MINN.
Bioclimatic registration of climate data.

Olgyay's Bioclimatic Analysis

(Victor Olgyay with Aladar Olgyay, Design With Climate: Bioclimatic Approach to Architectural Regionalism. Copyright (c) 1963 by Princeton University Press. Reprinted with permission of Princeton University Press.)

Figure 2.2



The Psychrometric Chart

Figure 2.3

building envelope, as well as other environmental control strategies, on achieving human comfort in buildings, given data on ambient climate conditions"[9]. The results of this work were summarized in Milne and Givoni (1979). Here, they described:

" ... the use of the psychrometric chart for energy-conservation designs and establishes a process whereby the designer can systematically match design solutions to climatic conditions. The method permits an identification of 'least purchased-energy' design strategies, first by utilizing the natural effects of sun, wind, and nighttime cooling, and, only when these are insufficient, by selecting appropriate mechanical equipment. Rather than the architect presenting the mechanical engineer with a design and the question, 'How much mechanical equipment do I need?', the approach implies that architect and engineer first ask, 'To what extent can natural energy systems be used?; Can we achieve human comfort conditions with no mechanical equipment?'; and, 'If mechanical systems are required, how can they best be integrated into the building design to minimize purchased energy use'"[10]?

Milne and Givoni then proceeded to define the human thermal comfort zone and several other strategy zones (such as humidification, evaporative cooling, high thermal mass and so forth) in terms of the psychrometric chart. The reader is referred to Milne and Givoni (1979) for details on how the boundaries of each zone were determined.

The work of Milne and Givoni made the leap towards architectural design that Olgyay's did not. They suggested that the designer determine " ... ambient climatic data for a given site and then identify the design strategies, alone or in combination, that

create human comfort conditions with the most appropriate means available"[11]. The "ambient climatic data" they referred to consisted of the average daily maximum and minimum temperatures along with the average relative humidity for each month. Their suggestion to use such a coarse database to describe the continuously changing climate limits their approach. They also failed to provide any clearly defined method for the application of the average temperature and relative humidity data to their charts.

2.3. THE BUILDING BIOCLIMATIC CHART

The psychrometric charts of Milne and Givoni were summarized in Watson and Labs (1983) as the "Building Bioclimatic Chart" which is reproduced in Figure 2.4. Watson and Labs divided the psychrometric chart into 18 possible zones and associated a strategy (such as Restrict Conduction, Promote Solar Gain and so forth) with each of the zones. It was this Building Bioclimatic Chart that was adopted as a database for all the subsequent research and analysis in this report. The Watson/Labs chart was adopted as it succinctly summarized the six charts presented in Milne and Givoni (1979).

Watson and Labs took the work of Milne and Givoni one step further in that they proposed a well-defined method for the application of climatic data to their chart. The data is entered

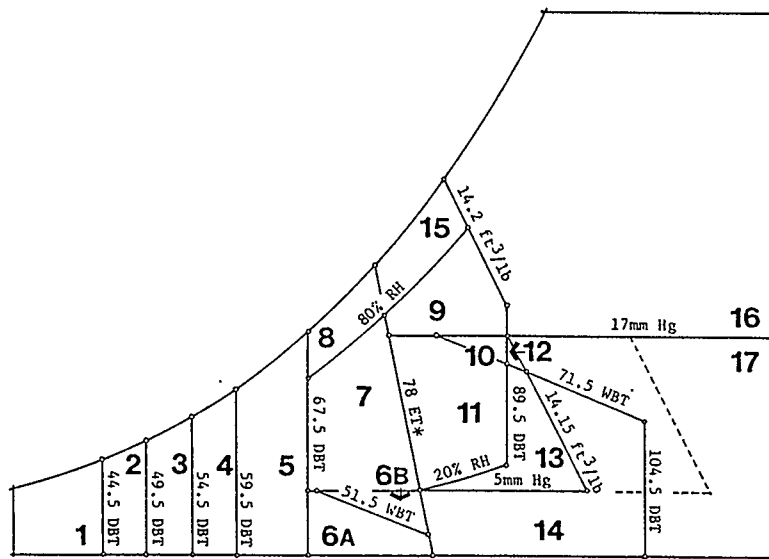


Figure 1. Building Bioclimatic Chart (after Givoni), showing psychrometric limits used for analysis reported in Tables 11-39.

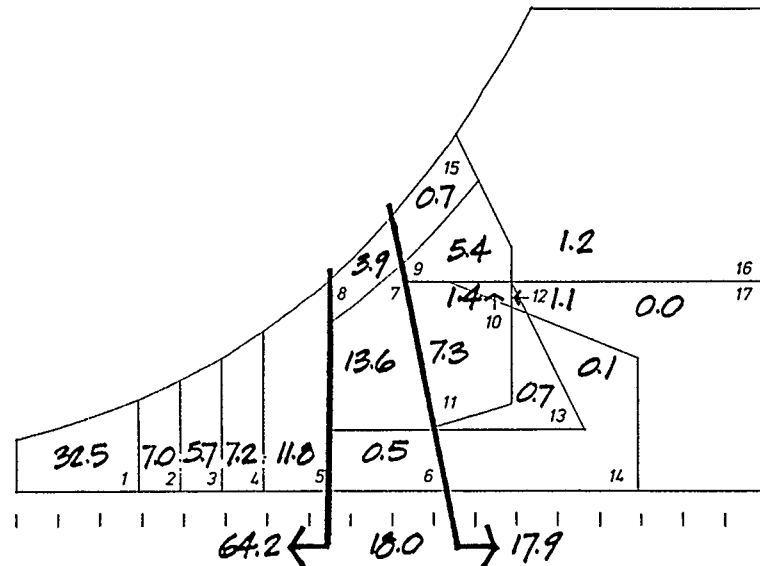
Table 1	Control Strategies
Identification of climate control strategies on the Building Bioclimatic Chart (adapted after Givoni).	
BIOCLIMATIC NEEDS ANALYSIS	
Total heating (< 68F)	1-5
Total cooling (> 78ET*)	9-17
Total comfort (68F – 78ET*, 5mm Hg – 80% RH)	7
Dehumidification (> 17mm Hg or 80% RH)	8-9, 15-16
Humidification (< 5mm Hg)	6A, 6B (14)
STRATEGIES OF CLIMATE CONTROL	
Restrict conduction	1-5; 9-11, 15-17
Restrict infiltration	1-5; 16-17
Promote solar gain	1-5
Restrict solar gain	6-17
Promote ventilation	9-11
Promote Evaporative cooling	11, 13-14 (6B)
Promote radiant cooling	10-13
Mechanical cooling	17
Mechanical cooling & dehumidification	15-16

The Building Bioclimatic Chart

(D. Watson and K. Labs, Climatic Design. Copyright (c) 1983 by McGraw-Hill Book Co. Reprinted by permission of McGraw-Hill Book Co.)

Figure 2.4

on the chart as the percentage of time that the climate is in each zone. An example of their analysis is presented in Figure 2.5. The number 13.6 in Zone 7 indicates that the climate is in the comfort zone for 13.6 percent of the year.



Watson and Labs' Bioclimatic Analysis

(D. Watson and K. Labs, Climatic Design. Copyright (c) 1983 by McGraw-Hill Book Co. Reprinted by permission of McGraw-Hill Book Co.)

Figure 2.5

The shortcoming of Watson and Labs' approach was like that of Milne and Givoni in that it was a manual method and thus required a much simplified database. Watson and Labs' method also produced only one chart to describe an entire year's climate. They presented computer generated databases for 29 American locations but there was no indication of how these databases were generated so their method was further limited to their 29

selected sites. Figure 2.4 indicates that Watson and Labs associated a corresponding "Strategy of Climate Control" with each zone. However their method of analysis consisted solely of producing a chart like Figure 2.5 and made no mention of how one might incorporate the Strategies of Climate Control into an analysis and so their method was much less powerful than it might have been.

2.4. BALANCING CONSERVATION AND SOLAR

In order to answer the question, 'What is the optimum mixture of energy conservation and solar energy?', a good deal of rigorous mathematical analysis has been performed[12]. It was the goal of researchers at the Los Alamos Laboratories to produce a much simplified method that could find widespread use amongst designers. This method has been developed and is discussed in detail in the Passive Solar Design Handbook (Los Alamos Laboratories, 1984).

The method can be summarized by the following arguments. Both conservation and passive solar are energy saving strategies that compete for investment dollars. Additionally, both strategies behave according to the law of diminishing returns. For example, doubling the RSI value of a wall might cost \$100. This increased insulation level might also save \$100 per year (from an initial \$200 per year to \$100 per year) in heating costs, giving a simple

payback time of one year. However, spending another \$200 to double the wall RSI again may only result in decrease in the heating cost to \$50 per year. The payback time for the second incremental improvement is now four years. Note that the comparison is between the 'incremental cost' and 'incremental savings'. The same argument holds true for the addition of a solar feature to a building with the first square metre of glazing contributing a larger fraction than each subsequent square metre.

"Because of these characteristics, it is usually true that a mix of conservation and passive solar strategies will produce the maximum energy savings for a given initial investment - an arrangement that allows both energy conservation and passive solar to work in their most cost-effective ranges.

"It is clear ... that the best strategy depends on the starting point and also on the climate. At each point in the design, it is possible to weigh the options and to determine the best strategy for increasing performance. An optimum mix is achieved when the incremental cost/benefit of each conservation option is just equal to the incremental cost/benefit of the passive solar strategy being used"[13].

The process of balancing conservation and solar has been reduced to a simple set of mathematical formulas which are presented in the Passive Solar Design Handbook (Los Alamos Laboratories, 1984).

To apply the formulas the designer must first decide between four types of passive solar design. These are direct gain, sunspace,

water wall, trombe wall or any combination thereof. It can be assumed that the client will have a good deal of influence on which system(s) would be included in the design. Once the basic system type has been selected the architect must choose amongst several 'Reference Designs'. The characteristics of each reference design are elaborated upon in detail in the Passive Solar Design Handbook (Los Alamos Laboratories, 1984). The reference designs for a direct gain building are reproduced in Figure 2.6.

System	Thermal Storage Capacity kJ/'C/sqm	Mass Thickness cm	Mass Area to Glazing Area Ratio	# of Panels	Glazing Nighttime Insulation
A1	612	5.1	6	2	no
A2	612	5.1	6	3	no
A3	612	5.1	6	2	RSI 1.6
B1	918	15.2	3	2	no
B2	918	15.2	3	3	no
B3	918	15.2	3	2	RSI 1.6
C1	1 224	10.2	6	2	no
C2	1 224	10.2	6	3	no
C3	1 224	10.2	6	2	RSI 1.6

Direct Gain Reference Designs

Figure 2.6

Then, probably in collaboration with the client, the designer must decide which of the reference designs will be investigated. The ease with which the analysis is performed lends itself to the investigation of several of the reference designs.

The designer must select a solar savings fraction (SSF) for his building. The solar savings fractions range from 0.1 which corresponds to a threshold solar building, to 0.8 for a building which will make extensive use of solar energy. A general guideline for the selection of a solar savings fraction is that lower values should be selected for colder climates. The implication of this is a building that leans more towards conservation rather than solar gain which concurs with the conclusions of recent studies of buildings in cold climates[14]. Then, along with the conservation factors (CF) from Appendix 17 of the Handbook, local construction costs of various building components such as wall insulation and glazings are inserted into the appropriate equations. The equations determine the optimum insulation levels for the various components as well as an optimum value for the number of air changes per hour. The method continues with the architect entering parameters such as the areas of the various building components, the load collector ratio (LCR) from Appendix 21 of the Handbook, the reference building characteristics and the number of heating degree days. The equations return the conservation and solar add-on costs and the auxiliary heating energy used. The method is explained at greater length in Section 3.3.

The designer must decide how 'far' to go with the strategies. This is most commonly decided by budget limitations on passive features or through a life-cycle cost analysis.

As a simplified method for estimating the cooling loads has yet to be developed, the analysis in this thesis only considers heating loads. It is recommended in the Passive Solar Design Handbook (Los Alamos Laboratories, 1984) that when designing for locations where cooling loads must be satisfied, the designer give preference to conserving features over solar gain features. This seems a logical recommendation. A large solar collecting area is more difficult to adequately shade and can only serve to add heat to a building during those times when it is least desired. Conversely, keeping the heat out with increased insulation in the walls and roof appears to be a good idea. The designer can easily shift the emphasis of a design from solar to conservation by keeping the value of the selected solar savings fraction in the 0.1 to 0.5 range.

The user of this method must have access to the Passive Solar Design Handbook (Los Alamos Laboratories, 1984) in order to obtain the conservation factors and load collector ratios required for the calculations. The method is further limited to those 219 locations for which the conservation factors and load collector ratios are available.

3. RESEARCH METHODOLOGY

The ability of any computer model to describe the real world is dependent upon the accuracy and completeness of the model's algorithms and the data upon which the model acts.

3.1. THE CLIMATE DATABASE

The traditional representations of weather data are limited by the averaging or sampling of data that is required in order to make them intelligible to humans. Inherent in any averaging or sampling process is a loss of detail. North America presently has many locations that gather weather data on an hourly basis giving 8 760 (365 days * 24 hours) sample points or records per year. As each record contains 31 distinct fields, the annual climate database contains 271 560 (8 760 records * 31 fields) measures of the climate. It is the vastness of this database that renders it inappropriate to anything but a computerized analysis.

The idea of a 'standard' database which is representative of a typical year's weather in a given location is of some value from the viewpoint of building system designers. The standard database facilitates the comparison of differing systems as well as of alternative theoretical models of system performance and thus allows designers to evaluate each system and to predict the

most useful system for a given location. It also permits the evaluation of a given system under conditions found in different locations. It is for this reason that 'Typical Meteorological Year' (TMY) databases have been developed by the National Climatic Center in Asheville, North Carolina. The characteristics of a meteorological year that makes it 'typical' include the following:[15]

- * Meteorological measures of the TMY, i.e., temperature, solar radiation, and wind, should have frequency distributions which are "close" to the long term distributions.
- * Sequences of the daily measures for the TMY should in some sense be "like" the sequences often registered at a given location.
- * Relationships among the different measures for the TMY should be "like" the relationships observed in nature.

The TMY databases are generated from long term datasets that are maintained at the National Climatic Center. These long term datasets consist of measurements taken over an approximately 20 year period beginning in the early 1950's. A so called 'empirical' approach was used to generate the TMY from the long term datasets. This method selected a 'typical' month for each of the twelve calendar months from the long term datasets using a statistical method and then concatenating the individual months to form the TMY. Hence, a TMY might contain data from January 1969, February 1955, and December 1960. The final selection of a typical month included considerations of the persistence of

weather patterns.

The TMY locations, known as SOLMET sites, contain measures of insolation levels as well as the standard TMY data fields. Some of these SOLMET sites have had their insolation data 'rehabilitated' in two possible ways: the existing horizontal insolation was corrected by applying a Standard Year Solar Noon Model and/or gaps in the hourly insolation data were filled in using the Total-Horizontal Solar Radiation Model. See Appendix 10 for more details on the generation of TMY data and its application to the model. Fresno is one of the SOLMET sites that contains rehabilitated insolation data.

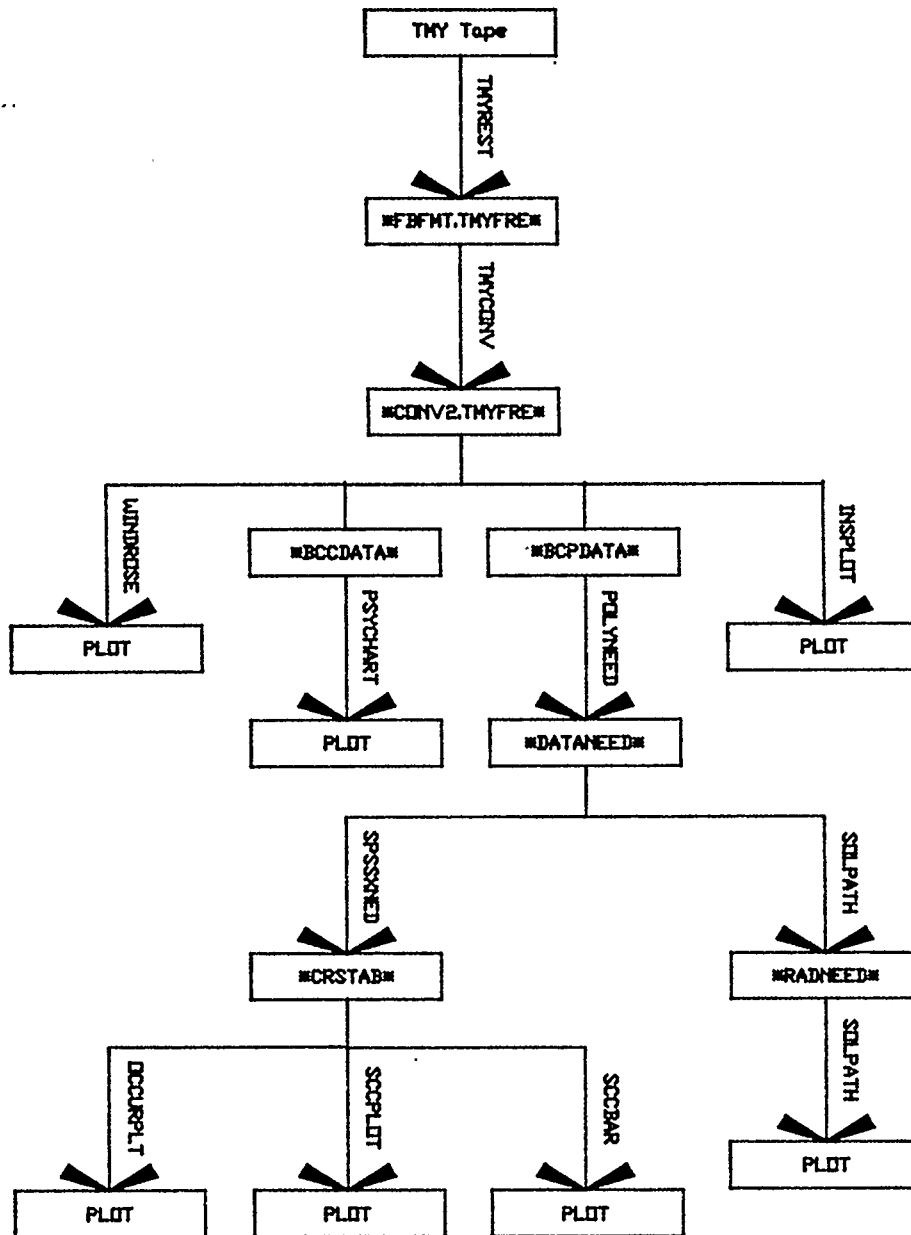
3.2. THE COMPUTER PROGRAMMES

The following eleven sub-sections contain descriptions of the computer programmes that comprise the Building Bioclimatic Analysis Model. Also included are general discussions of the programme algorithms and descriptions of databases generated by the programmes. A diagram of the model is given in Figure 3.1.

3.2.1. TMYREST

Arizona State University maintains a series of computer tapes that contain TMY data for the 26 SOLMET stations. The programme TMYREST loads the appropriate tape on the tape drive and copies it to file *FBFMT.TMYFRE*. File *FBFMT.TMYFRE* contains 8 760

records of weather data for Fresno, California.



BUILDING BIOCLIMATIC ANALYSIS MODEL FLOWCHART

Figure 3.1

3.2.2. TMYCONV

Several of the fields of data included in *FBFMT.TMYFRE* are not needed by the model. Conversely, *FBFMT.TMYFRE* does not contain the vapor pressure measurements required by the model. Programme TMYCONV reads *FBFMT.TMYFRE* one record at a time and calculates the vapor pressure and relative humidity from dry bulb temperature, dew point temperature and barometric pressure readings[16]. It then copies the month, day, hour, direct insolation, total horizontal insolation, dry bulb temperature, dew point temperature, wind speed and wind direction fields from *FBFMT.TMYFRE* along with the calculated vapor pressure and relative humidity to file *CONV2.TMYFRE* which serves as the model's database for Fresno. Figure 3.2 contains a partial listing of *CONV2.TMYFRE*. At this point *FBFMT.TMYFRE* can be eliminated from the hard disk as it is no longer needed.

3.2.3. PSYCHART

The ability to view the hourly trends of a location's climate is an asset in a bioclimatic study. Not only does this 'picture' of the climate provide the designer with an intuitive feel for the climate with respect to human comfort but is also useful in predicting whether a building might benefit from nighttime cooling provided by increased thermal mass. This point is elaborated upon in Section 4.5.

MON	DAY	HOUR	DIR INS	HOR INS	DB TEMP	DP TEMP	REL HUM	VAPOR PRESS	WIND DIR	WIND SPD
1	1	1	9999	9999	3793	3703	96	220	110	15
1	1	2	9999	9999	3703	3703	100	220	0	0
1	1	3	9999	9999	3703	3595	95	211	130	15
1	1	4	9999	9999	3595	3505	96	203	0	0
1	1	5	9999	9999	3505	3397	95	195	0	0
1	1	6	9999	9999	3505	3397	95	195	110	15
1	1	7	9999	9999	3505	3397	95	195	210	15
1	1	8	9	30	3505	3397	95	195	130	15
1	1	9	4	241	3505	3397	95	195	90	15
1	1	10	9	463	3595	3505	96	203	200	15
1	1	11	26	632	3703	3595	95	211	100	15
1	1	12	33	722	3991	3901	96	238	110	31
1	1	13	63	718	4207	3991	91	246	220	15
1	1	14	2865	1523	4801	4297	82	277	180	21
1	1	15	2338	1116	5108	4207	71	268	190	15
1	1	16	1205	588	5197	4207	68	268	300	46
1	1	17	24	91	4603	4100	82	257	310	21
1	1	18	9999	9999	4297	3991	88	246	240	21
1	1	19	9999	9999	3991	3793	92	228	290	26
1	1	20	9999	9999	3901	3793	95	228	300	31
1	1	21	9999	9999	3991	3901	96	238	300	41
1	1	22	9999	9999	3991	3901	96	238	300	62
1	1	23	9999	9999	3991	3901	96	238	310	51
1	1	24	9999	9999	3991	3901	96	238	320	31

The *CONV2.TMYFRE* Database for January 1

KEY

MON - Month (1 = January)	DAY - Day (1 = January 1st)
HOUR - Hour of the day	DIR INS - Direct Insolation (KJ/sqm) (9999 = 0)
HOR INS - Horizontal Insolation	DB TEMP - Dry Bulb Temperature (°F and hundredths)
DP TEMP - Dew Point Temperature	VAPOR PRESS - Vapor Pressure (Thousandths "Hg)
REL HUM - Relative Humidity (%)	WIND SPD - Wind Speed (m/s and tenths)
WIND DIR - Wind Direction (Degrees; 0 = North)	

Figure 3.2

The programme PSYCHART generates the Building Bioclimatic Charts of Appendix 1 which describe each month's hourly climatic conditions against the background of a psychrometric chart. The Building Bioclimatic Chart for the month of June is reproduced here in Figure 3.3.

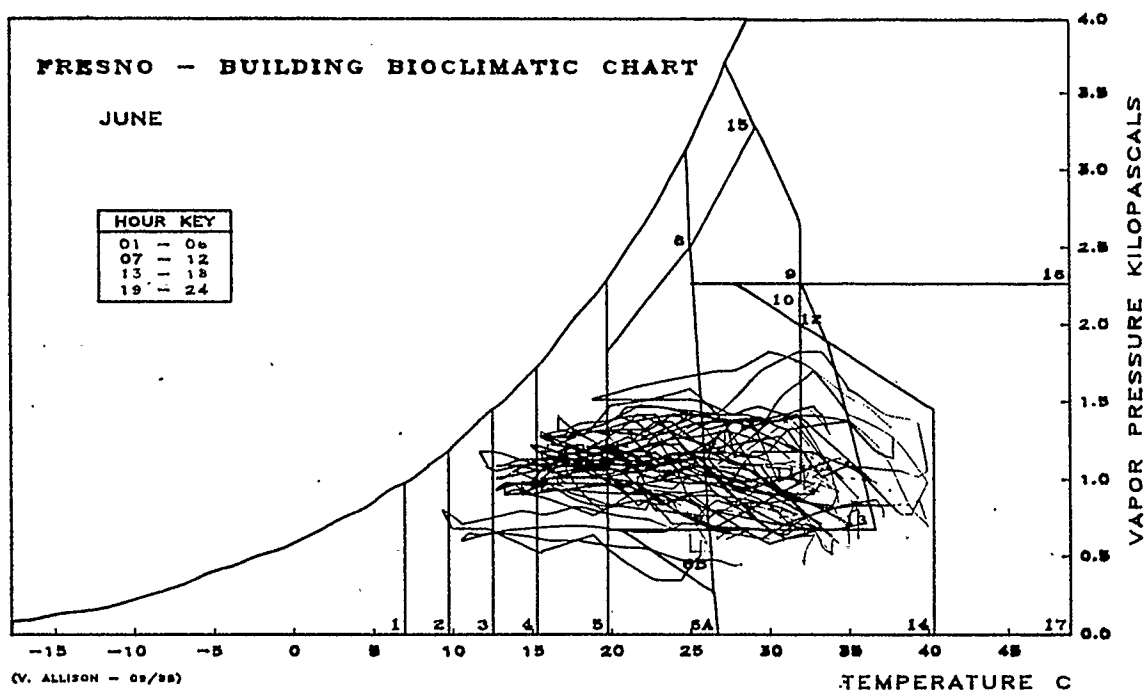


Figure 3.3

PSYCHART reads file *BCCDATA* which contains data that describes the lines that comprise the Building Bioclimatic Chart and then plots the chart lines along with its axis labels, title and key. PSYCHART then reads the temperature and vapor pressure fields of each record of *CONV2.TMYFRE* as a Cartesian coordinate pair

which it plots on the chart, moving to each new coordinate as it is read. It continues to plot the (temperature,vapor pressure) pairs for an entire month whereupon it generates a new chart for the next month. The plotted lines are color-coded according to the hour at which the temperature and vapor pressure were measured. This style of plot gives a clear indication of the hourly trends in the climate as one can follow the lines throughout the course of a day.

The second version of PSYCHART generates the same base plot but overlays the (temperature,vapor pressure) pairs as color-coded asterisks. Figure 3.4 shows this version of PSYCHART's output for the month of June. This chart is useful in visualizing the task of programme POLYNEED.

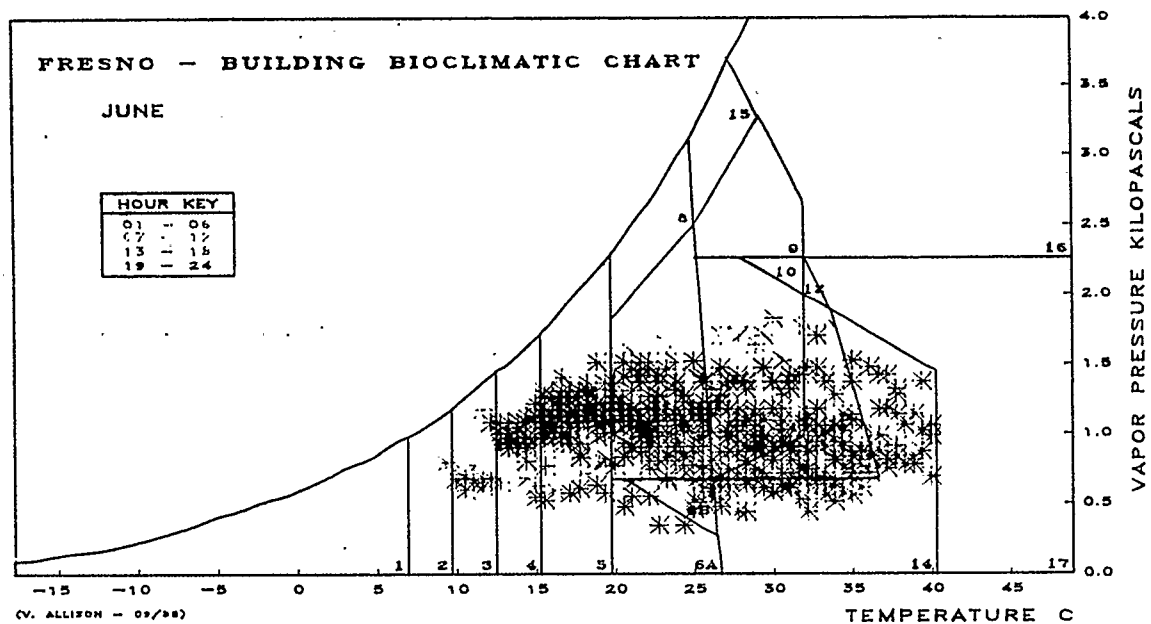


Figure 3.4

3.2.4. POLYNEED

POLYNEED is a programme that determines which of the 18 Building Bioclimatic Zones of Figure 2.4 each (temperature,vapor pressure) pair falls into. The coordinates of each vertex of the 18 zones were determined by extrapolating the lines of Figure 2.4 onto a standard psychrometric chart. These coordinate values are stored in file *BCPDATA*.

POLYNEED reads each month, day, hour, temperature and vapor pressure field of *CONV2.TMYFRE*, determines which zone the (temperature,vapor pressure) pair is in and then writes the zone, month, day and hour fields to file *DATANEED*.

3.2.5. SPSSXNED

File *DATANEED* still contains 8 760 records of data which is far too large for a manual analysis. The programme SPSSXNED performs a three-way crosstabulation (hour by zone by month) on file *DATANEED* using the SPSS-X[17] statistical analysis package that resides on Arizona State University's mainframe IBM computer. An inspection of Figure 3.5 in which the SPSS-X crosstabulation for the month of June is reproduced indicates that the climate of Fresno can now be described in terms of the number of (temperature,vapor pressure) pairs that fall into each zone at every hour. The crosstabulation chart lists the various zones as columns while each row corresponds to a specific hour. The numbers located in the crosstabulation cells represent the

19 OCT 35 FRESNO PSYCHROMETRIC ANALYSIS (POLYNEED)
 11:52:35 ARIZONA STATE UNIVERSITY 184 3091

MVS/SP

----- C R O S S T A B U L A T I O N O F -----
 BY BCPID BIOCLIMATIC ZONE
 HOUR CONTROLLING FOR..
 MONTH MONTH VALUE.. 6 JUNE ----- PAGE 1 OF 2

COUNT	BCPID										ROW TOTAL
	ZONE 02 HEATING 2	ZONE 03 HEATING 3	ZONE 04 HEATING 4	ZONE 05 HEATING 5	ZONE 06 HUMIDIFY 6	ZONE 07 HUMIDIFY 7	ZONE 08 COMFORT 8	ZONE 11 COOLING 12	ZONE 13 COOLING 14	ZONE 14 HUM-COOL 15	
HOUR											
1			3	9			13				30 4.2
2		1	3	15			11				30 4.2
3		1	5	19			5				30 4.2
4		2	6	17			5				30 4.2
5		2	6	18			4				30 4.2
6	1	2	8	15			4				30 4.2
7		3	6	13			7	1			30 4.2
8			4	9			14	3			30 4.2
9			2	6			15	7			30 4.2
10			1	3		1	14	10	1		30 4.2
11			1	1		1	8	15	4		30 4.2
12			1				7	15	3	4	30 4.2
(CONTINUED) COLUMN TOTAL	.1	11 1.5	50 6.9	146 29.3	.7	1.3	196 27.2	126 17.5	101 14.0	75 10.4	720 100.0

Figure 3.5

19 OCT 35 FRESNO PSYCHROMETRIC ANALYSIS (POLYNEED)
 11:52:35 ARIZONA STATE UNIVERSITY IBM 3091

HVS/SP

----- C R O S S T A B U L A T I O N O F -----
 BY 3CPI0 BIOCLIMATIC ZONE
 HOUR CONTROLLING FOR...
 MONTH MONTH VALUE.. 6 JUNE PAGE 2 OF 2

COUNT	3CPI0										ROW TOTAL
	ZONE 02 HEATING	ZONE 03 HEATING	ZONE 04 HEATING	ZONE 05 HEATING	ZONE 06 HUMIDIFY	ZONE 07 HUMIDIFY	ZONE 08 COMFORT	ZONE 11 COOLING	ZONE 13 COOLING	ZONE 14 HUM-COOL	
HOUR	2	3	4	5	6	7	8	12	14	15	
13			1				5	9	10	5	30 4.2
14				1		1	3	6	9	10	30 4.2
15				1		2	1	5	10	11	30 4.2
16				1		1	2	2	13	11	30 4.2
17				1		1	1	2	13	12	30 4.2
18				1		1	1	2	14	11	30 4.2
19				1	1		2	5	13	8	30 4.2
20				1	1	1	2	14	9	2	30 4.2
21				1	2		9	16	1	1	30 4.2
22				3	1		19	6	1		30 4.2
23			1	4			20	5			30 4.2
24			2	6			19	3			30 4.2
COLUMN TOTAL	1	11	50	146	5	9	196	126	101	75	720 100.0
	.1	1.5	6.9	20.3	.7	1.3	27.2	17.5	14.0	10.4	

Figure 3.5 (cont'd)

number of times that a (temperature,vapor pressure) pair is in each zone at each hour. Hence we see that at 1 a.m. in the month of June there are 3 occurrences in Zone 4, 9 occurrences in Zone 5 and 18 occurrences in Zone 7. Stated in another way, at 1 a.m. the climate of Fresno is in the comfort zone for 18 of June's 30 days. Note that the number of occurrences in each row adds up to 30 which is the number of days in June.

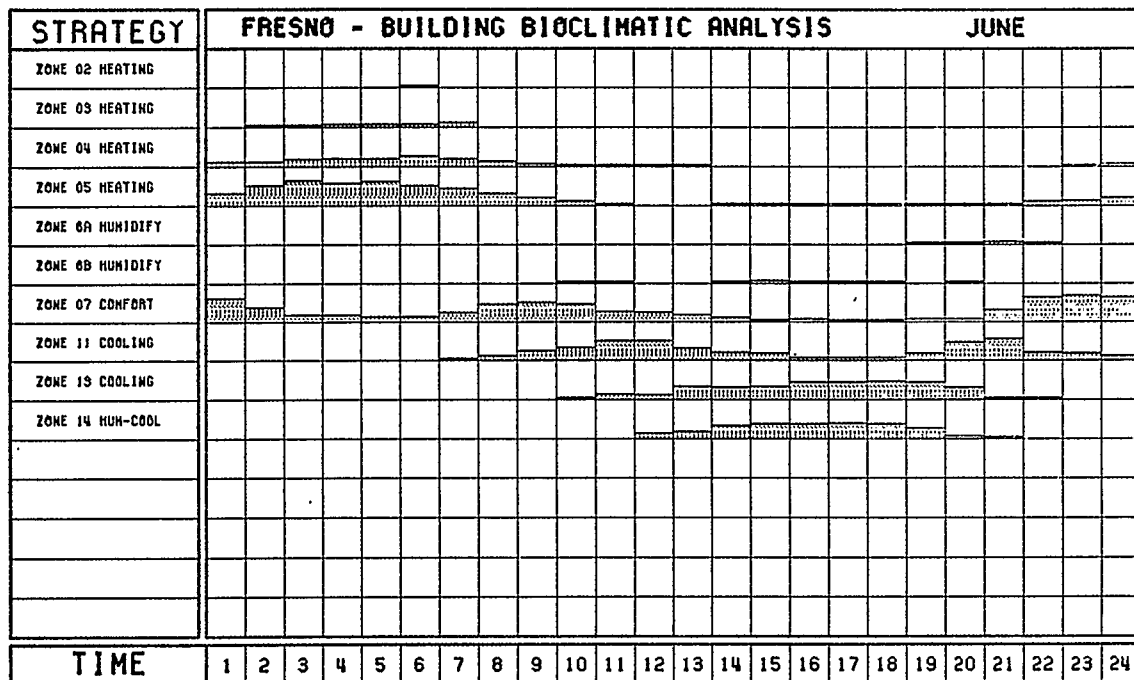
SPSSXNED generates file *CRSTAB* which contains fields describing the number of occurrences, hour, zone and month.

3.2.6. OCCURPLT

A much more compact description of Fresno's climate exists in the crosstabulations as compared with the reams of data in *CONV2.TMYFRE*. However, it is still difficult to visualize exactly what the trends in the climate are on an hourly basis. Programme OCCURPLT generates graphic descriptions of the information contained in the crosstabulations which now resides in file *CRSTAB*.

In the charts generated by OCCURPLT each column corresponds to a specific hour while the rows represent the zones. The cells are then shaded in proportion to the number of occurrences present in the corresponding crosstabulation cell. For example, the plot for June reproduced here in Figure 3.6 shows that at 1 a.m. Zone 7 is a little over half full. Actually, it is six-tenths full as

this corresponds to the 18 occurrences divided by the 30 days of June. Now note that the sum of the shaded cells in each column corresponds to a fully shaded cell which indicates that the climate is completely described on the chart.



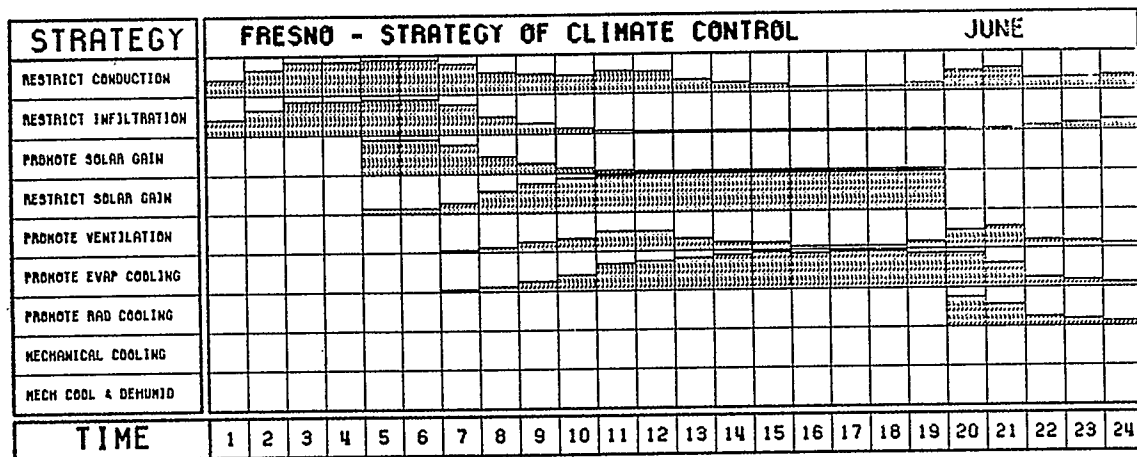
IV. ALLISON - 00/851

Figure 3.6

3.2.7. SCCPLOT

As is indicated in Figure 2.4, each zone of the Building Bioclimatic Chart has one or more corresponding 'Strategies of Climate Control' available to a designer. Programme SCCPLOT correlates the number of occurrences of each strategy (from file *CRSTAB*) with the appropriate climate control strategy(s) and

then overlays the percent occurrence of each strategy on the grid. Here, a completely shaded cell indicates a 100 percent occurrence of its corresponding strategy. Hence we see from Figure 3.7 that for June solar gain is an asset in the early morning and a definite liability after 8 or 9 a.m. Also, an evaporative cooling system is advantageous from the late morning through early evening hours. Conversely, cooling by ventilation is a relatively ineffective strategy for the designer to pursue even if wind is available for ventilation.



(V. ALLISON - 06/85)

Figure 3.7

3.2.8. SCCBAR

In an attempt to rank the importance of each strategy on a monthly and yearly basis programme SCCBAR takes the data from file *CRSTAB*, correlates the number of occurrences with the appropriate strategy(s) of climate control and then plots the percent occurrence of each strategy as a bar graph. If, as a

comparison between the SCCPLOT chart of Figure 3.8 and the SCCBAR chart of Figure 3.9 indicates, the fact that 'Restrict Conduction' is an indicated strategy for every hour of the 31 days of January shows up as a 100 percent bar in the SCCBAR plot.

Note that although the strategy of climate control would indicate 'Promote Solar Gain' as a useful strategy for every hour of January, the SCCPLOT and SCCBAR algorithms limit its application only to those hours when the sun is above the horizon. The same algorithm is also applied to the 'Restrict Solar Gain' zone. Conversely the 'Promote Radiant Cooling' strategy is only applicable during the nocturnal hours.

3.2.9. WINDROSE

It is an interesting academic exercise to inspect Figure 3.10 generated by SCCPLOT for the month of September and note that it indicates that the 'Promote Ventilation' strategy is potentially useful for passive cooling from 11 a.m. until 1 p.m. and then again from 6 p.m. until 9 p.m. However, this information does the real world designer little good if the location in question lies in an area without prevailing winds at those times. See Section 6.1.1 for a discussion of this limitation. Conversely, as the strategy of 'Restrict Infiltration' is important during the 'winter' months it is useful to know where the prevailing winds are coming from in order to consider what sort of landscaping or design features would prove beneficial in reducing

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL																	JANUARY																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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IV. ALLISON - 06/851

Figure 3.8

STRATEGY	FRESNO PSYCHROMETRIC CLIMATE CONTROL										JANUARY
RESTRICT CONDUCTION											
RESTRICT INFILTRATION											
PROMOTE SOLAR GAIN											
RESTRICT SOLAR GAIN											
PROMOTE VENTILATION											
PROMOTE EVAP COOLING											
PROMOTE RAD COOLING											
MECHANICAL COOLING											
MECH COOL & DEHUMID											
PERCENT	10	20	30	40	50	60	70	80	90		

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Figure 3.9

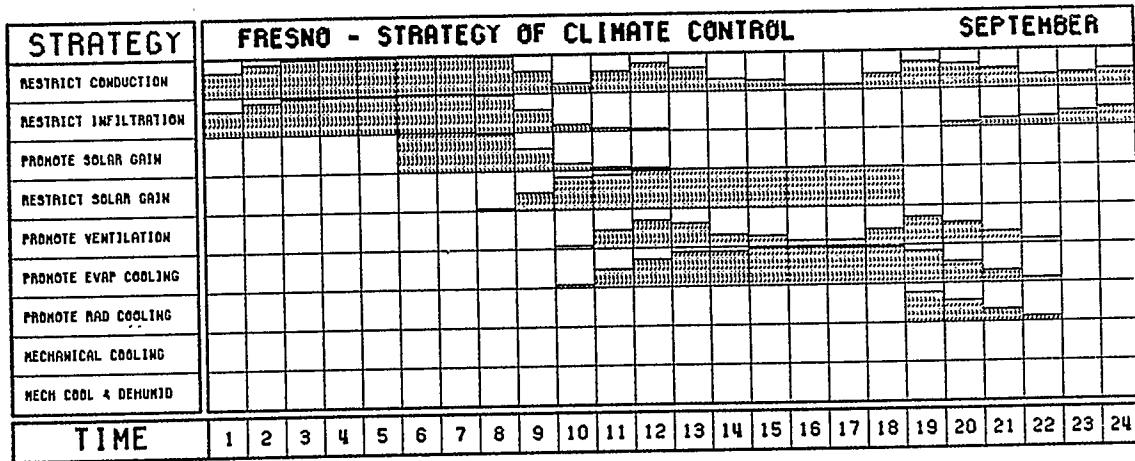
heat loss due to infiltration or convection.

Programme WINDROSE helps in this dilemma by generating monthly plots of wind speed and direction on a chart known as a windrose. WINDROSE does this by plotting a background indicating measures of the wind's speed and direction. It then reads the wind speed and wind direction fields of file *CONV2.TMYFRE*, converts them to polar coordinates, and overlays them on the background. Figure 3.11 displays the WINDROSE generated plot for the month of September.

3.2.10. SOLPATH

For each hour of the year when the (temperature,vapor pressure) pair falls into any of the Heating Zones 1 to 5 of Figure 2.4 it is a useful strategy to promote solar gain in an attempt to gain free heat. Conversely, when the (temperature,vapor pressure) pair falls into any of Zones 6 to 17, solar gain is a liability adding unnecessary heat and so the sun should be excluded from the building. Corresponding to each of the hours when solar gain would be either beneficial or detrimental the sun can be found in a predictable location in the sky[18].

Programme SOLPATH begins by reading file *DATANEED* which was generated by programme POLYNEED. File *DATANEED* contains 8 760 records of zone, month, day and hour fields. SOLPATH searches



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Figure 3.10

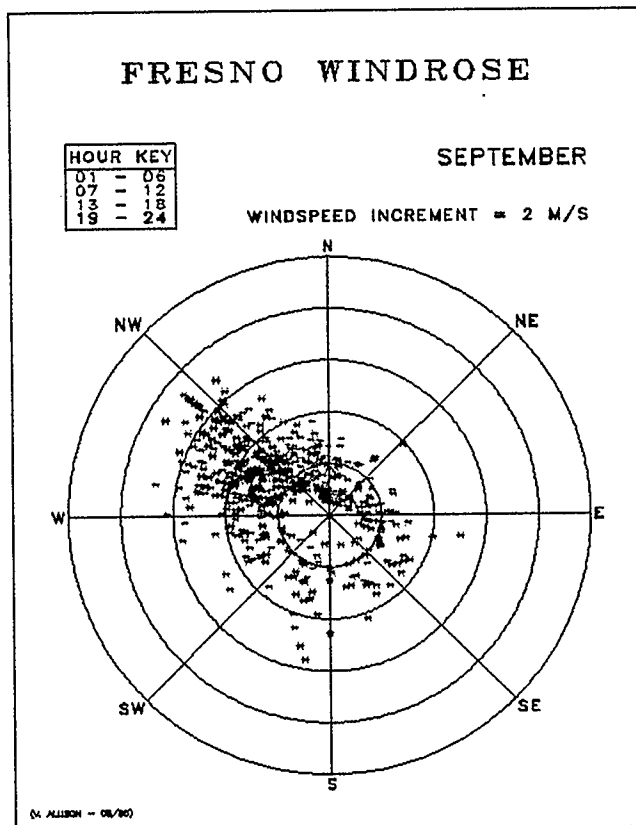
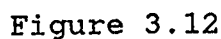


Figure 3.11

SOLPATH then generates a background plot of the sun path for the first and last day of each month (except for June and December when, because of the solstice, the first and twenty-first day are used). It then reads each month, day and hour field of *RADNEED*, determines the sun's azimuth and altitude for that month, day and hour, and overlays this information on the



background plot. Thus Figure 3.12 which is the SOLPATH output for April depicts in its shaded area the sun's position when solar gain is an asset and, in the unshaded area, when solar gain is a liability.

3.2.11. INSPLIT

Similar to the way that WINDROSE maps wind magnitude and direction, INSPLIT indicates how much insolation is actually falling on up to four surfaces during each hour on an average day of each month. INSPLIT begins by reading both the total horizontal insolation and the direct insolation fields for each hour of each month from file *CONV2.TMYFRE*. It computes each average hourly value of these two insolation levels for each month. Using the algorithms described in Baltas (1985) and Klucher (1979) it calculates and plots the average hourly insolation levels for up to four surfaces of any orientation and tilt. The user of INSPLIT is required to select the surface orientations before the programme is executed.

Figure 3.13 shows the INSPLIT output for the month of June. Azimuths of -90, 0 and 90 degrees correspond to surfaces facing due east, due south and due west respectively. A tilt of 90 degrees represents a vertical wall while a horizontal surface has a tilt of 0 degrees. Note the close correlation between the insolation levels for the northeast, east and southeast surfaces during the afternoon hours and a similar occurrence for the

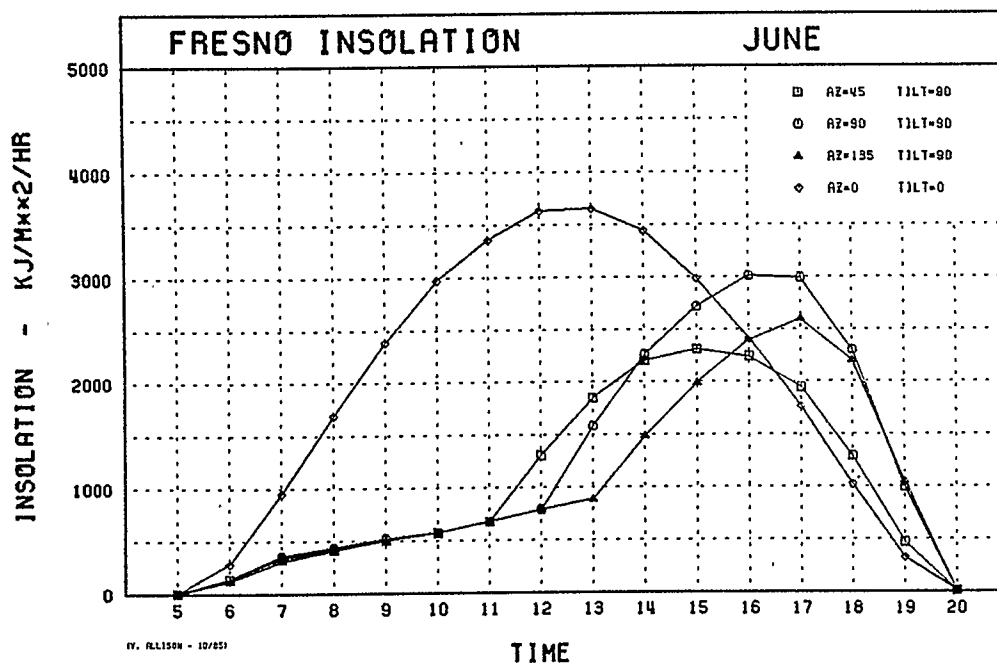
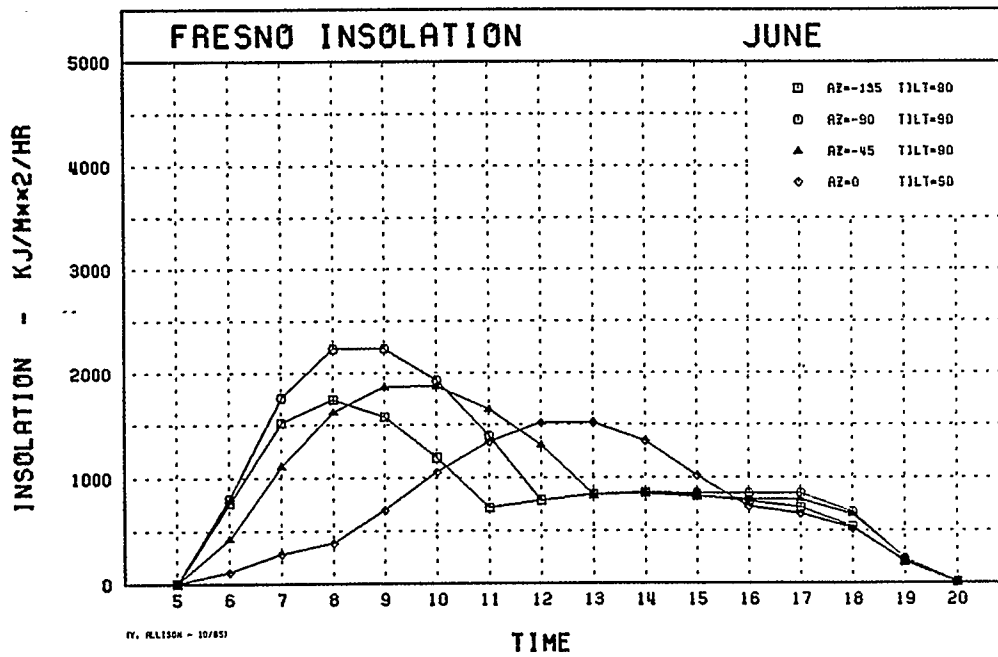


Figure 3.13

northwest, west and southwest surfaces during the morning hours. This can be attributed to the similar quantities of diffuse and reflected insolation impinging on these surfaces. It is only when the direct insolation component takes effect that each surface takes on unique values.

3.3. THE CONSERVATION / SOLAR SPREADSHEET

The spreadsheet analysis is a computerized implementation of the method of balancing conservation and solar that was presented in the Passive Solar Design Handbook (Los Alamos Laboratories, 1984). It was constructed with the Lotus 1-2-3 software package on an IBM Personal Computer[19]. The spreadsheet, an example of which is listed on pages 52 through 61 of this text, guides its user with a series of instructions which require entering various parameters such as the selected solar savings fraction. As each new entry is made the spreadsheet recalculates its output parameters. Thus by the time the user has entered all of the required inputs, the optimum insulation levels, energy use and economic figures have been recalculated and are waiting for the user's inspection and evaluation. It is thus a simple and quick process for the architect to compare several design alternatives. This spreadsheet type of analysis tool is advantageous for the user who is more interested in the bottom line answers rather than how they were derived as all of the calculation formulas are 'hidden' within the spreadsheet.

```

*****
*           B A L A N C I N G           *
*                                     *
*   C O N S E R V A T I O N   A N D   S O L A R   *
*****
*
***
*****
*****

```

LOTUS 1-2-3 Spreadsheet by Victor Allison - c November 1985

Reference: Passive Solar Design Handbook
 Total Environmental Action, Inc. /
 Los Alamos Scientific Laboratory /
 Los Alamos National Laboratory
 New York: Van Nostrand Reinhold Co., 1984.

General Notes:

The user of this spreadsheet must have access to the Passive Solar Design Handbook (or similar) to reference SSF and CF Tables.

SSF = 0.10 corresponds to a threshold passive solar building.
 SSF = 0.50 corresponds to a typical passive solar building.
 SSF = 0.80 corresponds to a major solar building.

All calculated parameters are surrounded by asterisks like this:

```

*****
Parameter = xxx.yy
*****

```

All parameters not surrounded by asterisks must be entered by the user.

Follow the instructions listed in Blocks 1 - 14.

-
- 1 - Select an initial Solar Savings Fraction (SSF) for the design and enter it under Selected SSF.
Enter 0.1 or 0.5 for the Lower Bound SSF and 0.5 or 0.8 for the Upper Bound SSF.

Lower Bound SSF		Selected SSF		Upper Bound SSF
0.10	<=	0.25	<=	0.50

- 2 - Enter the selected System Designation(s) and their Area Weighting(s)
Enter 0.0 for unused systems.
- 3 - From the Conservation Factor (CF) table enter those CF's whose SSF's form the lower and upper bounds of the selected SSF, i.e. lower SSF <= selected SSF <= upper SSF.

System Design	Area Weight CF	Lower SSF CF	***** Selected SSF CF	Upper SSF CF
SS xx	0.00	0.00	0.00	0.00
DG A1	1.00	1.00	1.34	1.90
WW xx	0.00	0.00	0.00	0.00
TW xx	0.00	0.00	0.00	0.00

Area Weighted Average CF = 1.34

-
- 4 - Price the costs for 2 wall systems in \$ per sq. metre
 using different RSI values (e.g. $RSI2 = 2 \times RSI1$)
 and enter the values under \$/sqm.
- 5 - Repeat for Floors, Ceiling, heated Basement, Perimeter,
 Glazing and Infiltration.
 Use Floors for unheated crawlspace.
 Use Perimeter for slab-on-grade.
 Use Basement for heated basement or other fully bermed wall,
 including floor losses.
 Enter 0.0 under the cost and a dummy value under RSI
 for unused constructions.

	RSI	\$/sqm
	-----	-----
Wall 1	1.9	32.29
Wall 2	6.3	45.75

 Incremental Cost of Wall Insulation = \$3.05 /RSI/sqm

	RSI	\$/sqm
	-----	-----
Ceiling 1	5.3	21.53
Ceiling 2	10.6	31.22

 Incremental Cost of Ceiling Insulation = \$1.83 /RSI/sqm

	RSI	\$/m
	-----	-----
Perimeter 1	3.5	6.56
Perimeter 2	7.1	22.97

Incremental Cost of Perimeter Insulation = \$4.66 /RSI/m

	RSI	\$/sqm
	-----	-----
Floor 1	1.8	0.00
Floor 2	2.6	0.00

Incremental Cost of Floor Insulation = \$0.00 /RSI/sqm

	RSI	\$/m
	-----	-----
Perimeter 1	3.5	0.00
Perimeter 2	7.1	0.00

Incremental Cost of Basement Insulation = \$0.00 /RSI/m

	RSI	\$/sqm
	-----	-----
Glazing 1	0.11	53.82
Glazing 2	0.28	96.88

Incremental Cost for One Added Glazing = \$43.06 /sqm
\$246.06 /R/sqm

	ACH	\$/cum
	-----	-----
Infiltr 1	1.00	3.43
Infiltr 2	0.75	3.71

Incremental Cost for Infil. Decrease = \$1.12 /(1/ACH)/cum

-
- 6 - Estimate the cost of the sunspace in \$ per sqm of glazing and enter it.
Enter 0.0 if there is no sunspace.

Feature	\$/sqm
-----	-----
Sunspace	0.00

-
- 7 - Determine a reasonable estimate of the sunspace amenity (appraisal) value and enter it.
This value should be less than that of the Block 6.
Enter 0.0 if there is no sunspace.

	\$/sqm

Sunspace	0.00

-
- 8 - Enter the sunspace's Total Glazed Area and Projected Area.
Enter 1.0E+99 if there is no sunspace.

Total Glazed Area =	*****sqm
Projected Area =	*****sqm

9 - For the other passive features enter the cost of the feature glazing the replaced opaque wall and the moveable insulation (if used). Enter 0.0 for unused features.

Direct Gain Glazing	=	\$96.88 /sqm
Direct Gain Opaque Wall	=	\$34.12 /sqm
Direct Gain Night Insulation	=	\$0.00 /sqm
Water Wall Glazing	=	\$0.00 /sqm
Water Wall Opaque Wall	=	\$0.00 /sqm
Water Wall Night Insulation	=	\$0.00 /sqm
Trombe Wall Glazing	=	\$0.00 /sqm
Trombe Wall Opaque Wall	=	\$0.00 /sqm
Trombe Wall Night Insulation	=	\$0.00 /sqm

Incremental Costs of Passive Solar Features are:

Sunspace	=	\$0.00 /sqm of projected area
Direct Gain	=	\$62.76 /sqm of projected area
Water Wall	=	\$0.00 /sqm of projected area
Trombe Wall	=	\$0.00 /sqm of projected area

Area Weighted Passive Solar Cost = \$62.76 /sqm

Optimum Values are:

Buildable Values are:

R wall	=	2.5	----->	2.5
R ceiling	=	3.3	----->	3.3
R perimeter	=	1.4	----->	1.4
R floor	=	ERR	----->	*****
R basement	=	ERR	----->	*****
R glazing	=	0.3	----->	2 panes
ACH	=	0.41	----->	1.00

NOTE: Enter 1.0E+99 for Buildable R values when the optimum is ERR or 0.0

10 - Enter the following building dimensions to calculate the BLC.
 Enter 0.0 for unused components.
 $\text{Wall area} = (\text{perimeter} \times \text{ceiling height}) - (\text{nonsouth window area} + \text{south window area}).$
 Use Perimeter for slab-on-grade construction.
 Use Floor for vented crawl space.
 Use Basement for heated basement or other fully-bermed wall,
 including floor losses.
 $\text{Combined Floor Area} = \text{area of storey 1} + \text{area of storey 2} + \dots$

Wall Area	=	80.4	sqm
Ceiling (Roof) Area	=	139.4	sqm
Perimeter Length	=	50.3	m
Ground Floor Area	=	0.0	sqm
Basement Wall Length	=	0.0	m
E, N, W Windows	=	6.0	sqm
Ceiling Height	=	2.4	m
Combined Floor Area	=	139.4	sqm
Air Density Ratio	=	1.00	

Component	BLC	

Wall	2779.3	KJ/DD
Ceiling	3651.1	KJ/DD
Perimeter	2422.1	KJ/DD
Floor	0.0	KJ/DD
Basement	0.0	KJ/DD
Windows	1605.9	KJ/DD
Infiltration	9855.6	KJ/DD

Total BLC =	20314.1	KJ/DD

11 - From the Load Collector Ratio (LCR) table enter those LCR's whose SSF's form the lower and upper bounds of the Selected SSF, i.e. Lower SSF <= Selected SSF <= Upper SSF. Enter 0.0 for the Upper and Lower bounds of unused systems.

	Lower Bound SSF		Selected SSF		Upper Bound SSF
	-----		-----		-----
	0.20	<=	0.25	<=	0.30

	Lower Bound LCR		Selected LCR		Upper Bound LCR
	-----		-----		-----
Sunspace	0		0.0		0
Direct Gain	125		97.0		69
Water Wall	0		0.0		0
Trombe Wall	0		0.0		0

Area Weighted Average LCR = 97.0

Net Passive Solar Projected Area = 10.2 sqm

Sunspace	=	0.0 sqm	(	0.0%)
Direct Gain	=	10.2 sqm	(	100.0%)
Water Wall	=	0.0 sqm	(	0.0%)
Trombe wall	=	0.0 sqm	(	0.0%)

-
- 12 - If a High-Mass Direct-Gain building is selected enter the System Designation, Thermal Storage Capacity, Mass Thickness, Mass-Area-to-Glazing-Area Ratio, No. of Glazings and Night Insul. from Figure 0-2, p. 155, PSDH. Enter the Thermal Storage Capacity and Mass Thickness in the parallel English measure spreadsheet and the conversion to SI units will be performed. The units of the Thermal Storage Capacity are: kJ/°C/sqm. Enter 0.0 for all parameters if unused.

Sys Des'gn	Therm Stor Cap	Mass Thkns (cm)	Mass Area/ Glaz Area Ratio	# of Glazings	Night Insul
A1	612	5.1	6	2	no
	*****	*****			

 Required Mass Area = 61.3 sqm

-
- 13 - To calculate the Conservation Add-On Cost an assumed reference level (or base case values) for the following parameters must be entered. Enter 1.0E+99 for unused values. Infiltration costs are determined from Table N-2 PSDH.

Component	Base Case	Units	***** Add-On Cost
Wall	1.9	RSI	\$147.26
Ceiling	2.4	RSI	\$229.73
Perimeter	0.0	RSI	\$328.23
Floor	*****	RSI	\$0.00
Basement	*****	RSI	\$0.00
Windows	1	# panes	\$260.08
Infiltration	1.50	ACH	\$500.00
Total Conservation Add-On Cost =			\$1,465.30
Solar Add-On Cost =			\$641.02
Total Add-On Cost =			\$2,106.32

14 - To calculate the auxiliary heat used enter the # of Degree Days.

DD = 1472

Auxiliary Heat = 22.43 GJ

15 - For comparison purposes the BLC is recalculated using the base-case parameters of Section 12.
Then the auxiliary heat of the base case building is calculated.

Base Case BLC = 32944 KJ/DD

Auxiliary Base Case Heat = 48.49 GJ

16 - The energy saved by the combined conservation and solar strategies is:

Aux Heat (Base Case) = 48.49 GJ/year
Aux Heat (Cons + Solar) = 22.43 GJ/year

26.07 GJ/year

The design costs \$2,106 more than the base case

but saves 26.07 GJ/year in energy

which is an investment of \$80.81 per GJ saved annually

4. ANALYSIS OF THE MODEL'S OUTPUT

This chapter is divided into twelve monthly sub-sections each of which begins with a general discussion of the model's outputs. The climate control strategies indicated are evaluated in terms of the ability of the climate to meet a building's needs. This evaluation is based on the availability of wind (as indicated by WINDROSE) to meet any ventilation needs or the availability of insolation (as indicated by INSLOT) to meet any solar gain needs. It has been assumed that only those insolation levels with a direct component are capable of adding thermal energy to the building. This shortcoming is discussed in Chapters 6 and 7. For a detailed discussion of how a monthly analysis is performed see Section 4.5 on the month of May.

In order to facilitate the analysis of the model's outputs with respect to a design the following assumptions were made:

- * The building has a flat roof.
- * It has a rectilinear footprint with its principle axis running due east-west.
- * It is located on an open site unaffected by topography, vegetation or surrounding structures.

4.1. JANUARY

The SCCPLOT output for January does not yield any startling information. As is indicated in the PSYCHART plot the Fresno climate is quite cold and never extends beyond the lower limits of Zone 5. Consequently, the building of a well insulated structure with an effective air/vapor barrier are indispensable climate control strategies.

The building should capture the available insolation to reduce any reliance on mechanical heating. The sun rises approximately 20 to 30 degrees south of east and, as is seen from the INSPLOT output, provides little opportunity for solar gain on anything but the south-facing wall, the flat roof or the west wall during the late afternoon hours. This is a result of the assumption that only those insolation levels with a direct component can contribute significant solar gains. Consequently, any south or west facing solar apertures should be unshaded during these times. The prevailing winds fall along the northwest - southeast axis which indicates the opportunity for designing an effective windbreak and protected entrance.

4.2. FEBRUARY

Although the PSYCHART output now indicates a few excursions of the climate into the comfort zone during the afternoon hours, the number of occurrences are so few that they can be ignored. The sun is now rising closer to due east with the INSPLIT output showing the possibility of obtaining some direct insolation on the east and west facades during the early morning and late afternoon hours respectively. Consideration should be given to the possibility of using a low mass internal construction type on the east side. This would allow the low sun to quickly add heat to this side of the building on the cold mornings.

4.3. MARCH

The March climate is still quite cold during the evening through morning hours but there are now a significant number of excursions beyond the heating zones. The SOLPATH chart indicates that sometime near the end of March solar gain starts to become a liability during the afternoon hours.

Any cooling that is needed during the afternoon can easily be met through natural ventilation as the windrose indicates prevailing northwest - southeast winds. As the indicated needs for evaporative cooling or ventilation account for only about 2 percent of the month these strategies probably can be disregarded

without precluding the occupant's comfort. However, the prevailing northwest - southeast winds indicates that the potential for cooling by ventilation does exist if it is needed.

4.4. APRIL

The climate of April initially appears to be a natural extension of the warming trend of March with its cold mornings and generally comfortable afternoons. The SOLPATH output indicates that the month seems to have its afternoon needs alternate between admitting and excluding the sun for several days at a time. This is perhaps indicative of several days of persistent clouds keeping the afternoon temperatures in the heating zones. This assumption was in fact borne out by an inspection of the 'minutes of sunshine' and 'sky cover' fields of *FBFMT.TMYFRE* which indicated alternating sunny and cloudy periods. The INSPLIT chart for west facing surfaces now indicates that they are receiving in excess of 2 000 kilojoules per square metre of radiant energy. This could possibly lead to extensive overheating if there are large expanses of unshaded west facing glass. The SOLPATH chart does not really help us in this case due to the oscillating heating/cooling needs. Possible design solutions for this situation are the use of adjustable shading devices such as shutters which could be set to admit or exclude insolation as the climate dictated. It is also possible that the times when solar gain is indicated as an asset

corresponds to the cloudy periods and so the use of shading devices would be redundant. The use of a thermal mass in any west facing rooms could also help to dampen any temperature fluctuations while storing heat for the chilly evenings.

For those afternoons when cooling is needed it appears that the northwest - southeast winds should be able to meet most of the needs.

4.5. MAY

The climate of May was selected to provide a detailed discussion of the analysis method used in this section as it illustrates the application of the model to both heating and cooling problems. The outputs of all the models for May are reproduced here in Figures 4.1 through 4.7.

An inspection of the PSYCHART output in Figure 4.1 indicates that the May climate shifts between chilly late nights and early mornings, through the comfort zone and into the overheated zones during the afternoon hours. This is further borne out by SCCPLOT in Figure 4.3 which shows the importance of the restricting conduction and infiltration in the early morning and late evening hours. The promote and restrict solar gain cells are seen to be reverse mirror images of each other with the transition area occurring during mid morning. Both the SCCPLOT chart and the

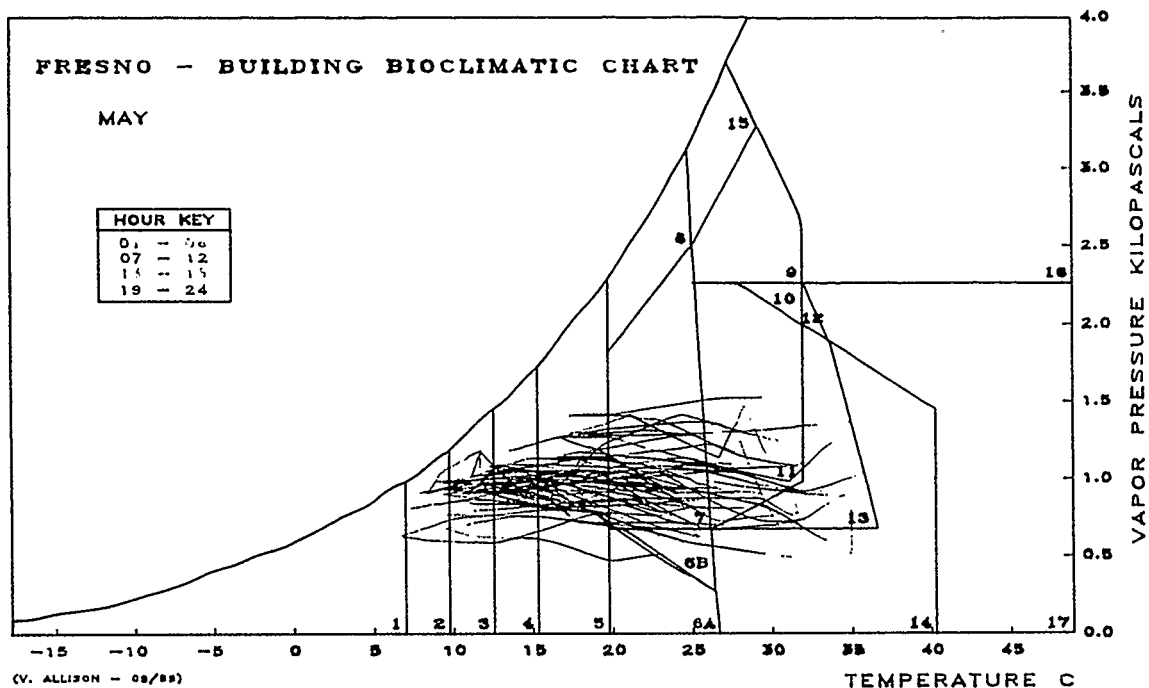


Figure 4.1

STRATEGY	FRESNO - BUILDING BIOCLIMATIC ANALYSIS MAY																							
ZONE 01 HEATING																								
ZONE 02 HEATING																								
ZONE 03 HEATING																								
ZONE 04 HEATING																								
ZONE 05 HEATING																								
ZONE 06A HUMIDIFY																								
ZONE 06B HUMIDIFY																								
ZONE 07 COMFORT																								
ZONE 11 COOLING																								
ZONE 13 COOLING																								
ZONE 14 HUM-COOL																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

(V. ALLISON - 02/85)

Figure 4.2

SOLPATH chart of Figure 4.4 indicate the need for solar gain from 5 a.m. until about 10 a.m. The SOLPATH chart shows that the early morning sun is centered around due east at 8 a.m. and has an altitude of about 35 degrees. The sun's relatively low altitude and eastern azimuth during morning hours coupled with the demonstrated need for heating suggests that the building might easily be designed to take advantage of the sun's energy. The INSPLOT chart of Figure 4.5 indicates that there is in excess of 1 500 kilojoules per square metre falling on east facing surfaces between 7 a.m. and 11 a.m. Hence we see that direct insolation is available if desired.

The early morning is the time when people usually rise from their warm beds and so would appreciate some extra warmth in their surroundings as they go about preparing for the new day. This fact suggests that an area like a kitchen or bathroom should have an eastern orientation as people are likely to be there during the mornings. Coupling this with the already demonstrated afternoon cooling problems suggests that the space should be designed to quickly take advantage of the heat and have it dissipate before the afternoon period. Consequently, a lightweight construction type should be considered for this section of the building as it has the properties of quickly converting the insolation into heat while having a low thermal storage capacity.

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL MAY																							
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

(V. ALLISON - 06/85)

Figure 4.3

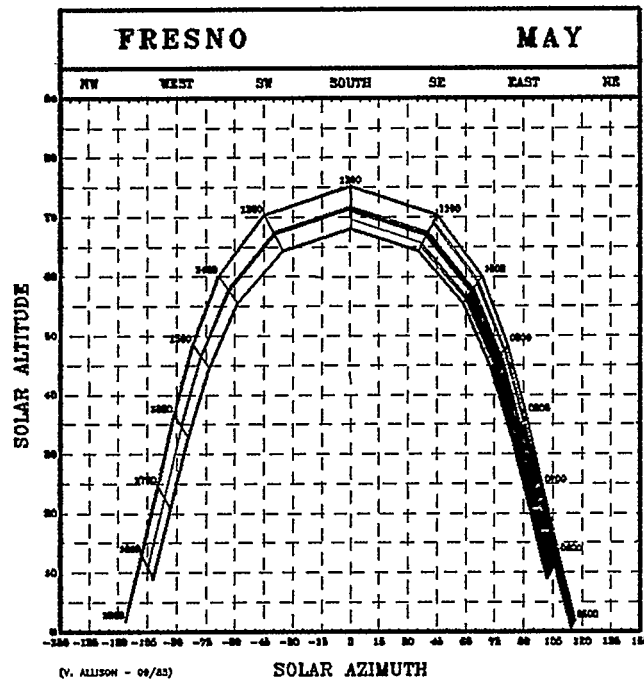


Figure 4.4

From about 11 a.m. through 2 p.m. the sun is high in the sky and so its incidence on any south facing glazings can be easily controlled with a fixed shading device. This potential problem is further alleviated by the sun's large incidence angle on south facing surfaces and, as is indicated by the INSPLIT chart, the insolation level peaks at just over 1 500 kilojoules per square metre compared with the near 3 500 kilojoules per square metre on the flat roof. The high insolation levels on the roof indicate the importance of providing it with adequate insulation and venting as well as the use of a light colored surfacing material to reflect the sun's rays.

The SCCPLOT, SOLPATH and INSPLIT charts all indicate the need for prudent design decisions to avoid the overheating potentials of the afternoon through early evening. The high insolation levels on west facing surfaces coupled with the low sun angles indicate the urgency of this problem. When the insolation level on a west facing surface peaks at 4 p.m. at 3 000 kilojoules per square metre (see Figure 4.5) the sun's altitude is in the neighborhood of 35 degrees. At this altitude a standard overhang type shading device would have to be impractically deep. Possible solutions to this dilemma include restricting or eliminating any west facing glazings, installing exterior shutters or rolling blind type shading devices, using vegetation to shade the glazing and using a heat mirror or heat absorbing type of glazing amongst others. As we have previously seen it is advantageous to have

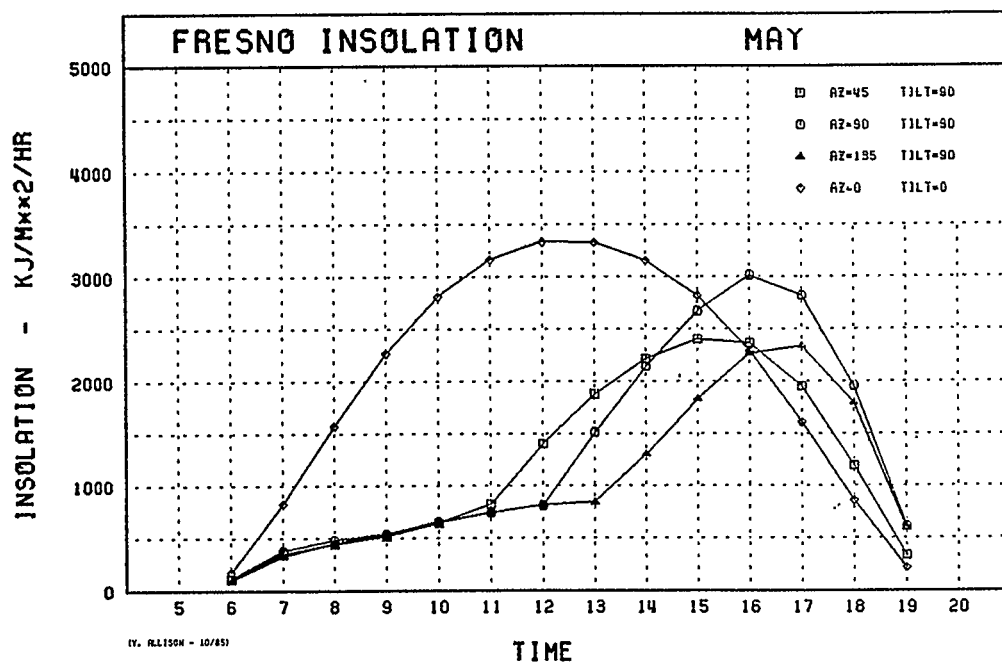
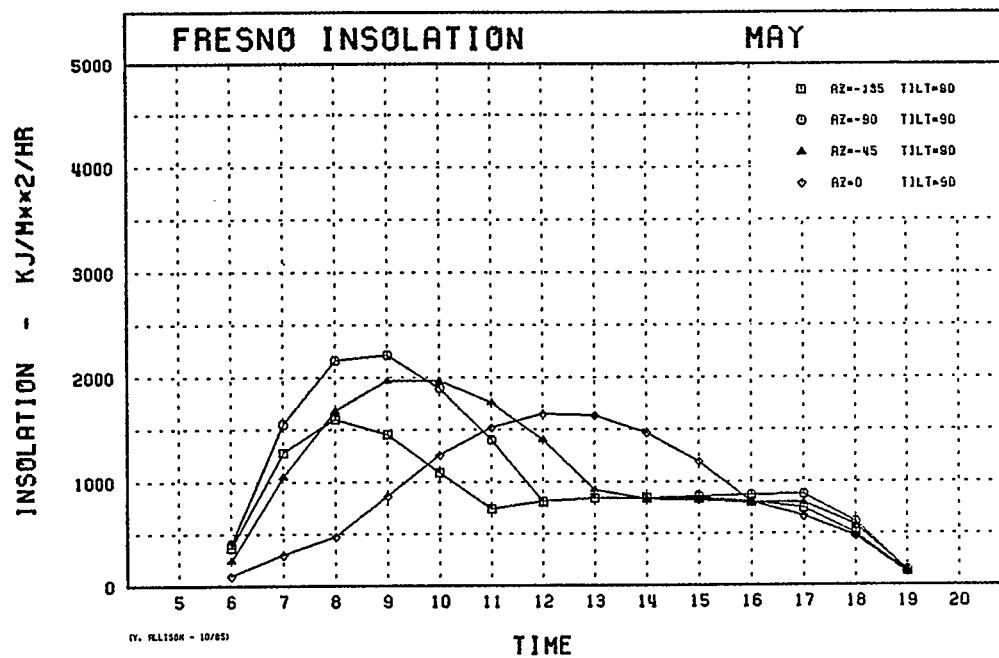
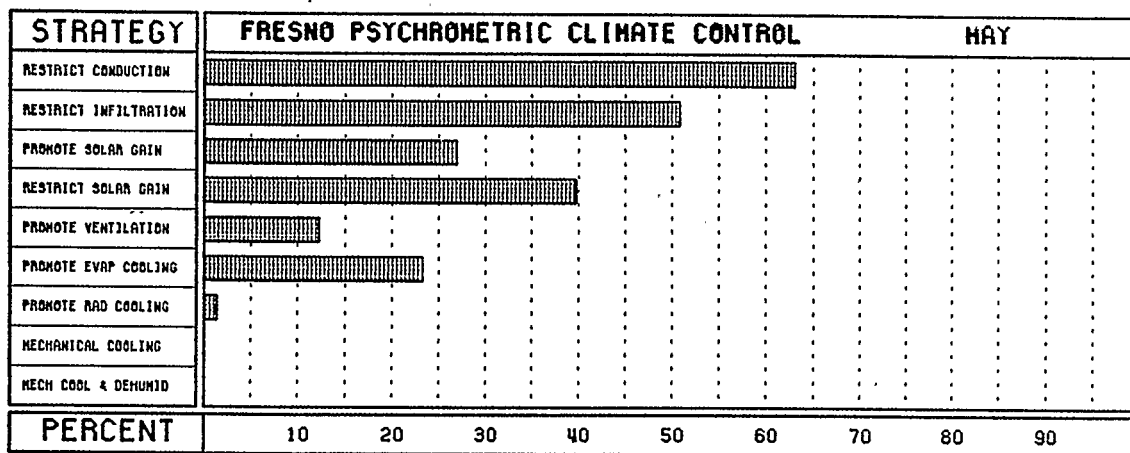


Figure 4.5

west facing glazing during the winter months so its elimination is probably not the best choice. Exterior shading devices are probably the most effective and least expensive of the choices but their use requires human intervention which may or may not be a good idea depending on the client. It would be wise to consider incorporating a thermal mass with the west facing rooms. This mass would help to temper any thermal swings and also serve to store some heat for re-radiation during the cool nights and early morning.

The SCCPLOT chart indicates that both ventilation and evaporative cooling are good strategies to design for during the afternoon hours. The evaporative cooling strategy appears to be the more useful and this is corroborated by the SCCBAR plot of Figure 4.6 which shows ventilation and evaporative cooling as being effective about 12 and 23 percent of the time respectively. With ventilation being an effective strategy during the afternoon hours, a comparison with the WINDROSE plot of Figure 4.7 shows that the prevailing wind between 1 p.m. and 8 p.m. is from the northwest and ranges from 2 to 8 metres per second in velocity. Hence, the designer would be wise to allow for cross-ventilation from the north and/or west sides.

A re-inspection of the PSYCHART plot shows that the climate swings from the heating zones in the late evening and early morning to the cooling zones during the afternoon hours. It is



(V. ALLISON - 02/85)

Figure 4.6

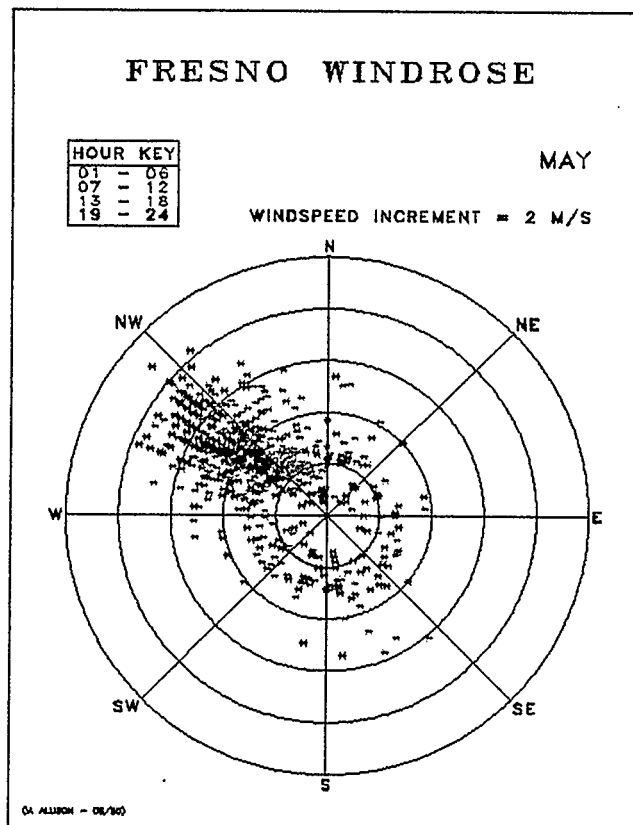


Figure 4.7

useful in this type of climate to consider employing a massive this mass serves structure, ventilating it during the evening and morning with cool outdoor air. Then, during the afternoon, to absorb radiant heat from any occupants thereby cooling them. The placement of this mass and/or the ventilation paths in the building need to be evaluated with respect to space planning considerations as few people would appreciate occupying a cooled space during anything but the afternoon hours.

The design suggestions elaborated upon in this section should not be considered in isolation as the climate of May constitutes but one twelfth of the total picture.

4.6. JUNE

The climate of June is similar to that of May except that it is slightly hotter and has a wider spread in vapor pressure. The strategies of climate control are similar to that of May except that evaporative cooling is now mandatory from the late morning through early evening hours. Radiant cooling, although indicated as a strategy, is not viable to a location like Fresno as it is dependent on cold, clear nights and so can be ignored.

4.7. JULY

Although the extreme afternoon temperatures of July are not much hotter than those of June, the early morning temperatures seldom fall into or below Zone 5. This fact begins to reduce the effectiveness of trying to store any nighttime coolth in a thermal mass. A thermal mass would still be a useful feature of a design as it can serve to temper the daytime temperature swings by absorbing unwanted heat. In this case the nighttime flushing of the mass would help reduce the re-radiation of the stored heat.

Again, evaporative cooling is mandatory even though ventilation seems to be effective for a couple of hours either side of 11 a.m. and 9 p.m. Mechanical cooling is now indicated for some of the afternoon hours. As SCCBAR indicates that this is for approximately 2 percent of the time it is likely that a compressor cooling system can be excluded without causing the building's occupants excessive discomfort. This assumes that the building's design allows it to take advantage of the available passive cooling techniques.

4.8. AUGUST

The climate of August, although similar to that of July is starting to show signs of abatement as SCCBAR indicates a reduction in the percent occurrence of 'Restrict Solar Gain', 'Promote Ventilation' and 'Promote Evaporative Cooling'. August is again a time to keep the building and its windows shaded, utilize the prevailing northwest wind and use evaporative cooling.

4.9. SEPTEMBER

The beginnings of consistently needing early morning solar gain appear in September (actually the end of August). Both wind and evaporation are effective for cooling during the afternoons. The nighttime cooling of a thermal mass shows signs of returning as an effective strategy due to the cool mornings.

4.10. OCTOBER

The October climate is easily described as having cold nights and mornings that warm up nicely during the afternoons. The building welcomes the early morning sun but still wants to keep it from its southern and western exposures.

The prevailing northwest wind is useful for cooling during the afternoon as is the evaporative cooler. The nighttime flushing of a thermal mass, although useful, is becoming less important due to the few excursions of the climate beyond the comfort zone.

4.11. NOVEMBER

Solar gain along with reducing conduction and infiltration are the only viable passive strategies for November. The SOLPATH plot indicates an altitude cutoff value of about 38 degrees; the south facing shading devices should now permit the sun to strike the facade. The SCCBAR plot indicates the percent occurrence of the 'Restrict Solar Gain' strategy is about 4% and so it can be ignored.

The windrose shows an almost even distribution of winds so no specific recommendations can be made for the design of wind sheltering features.

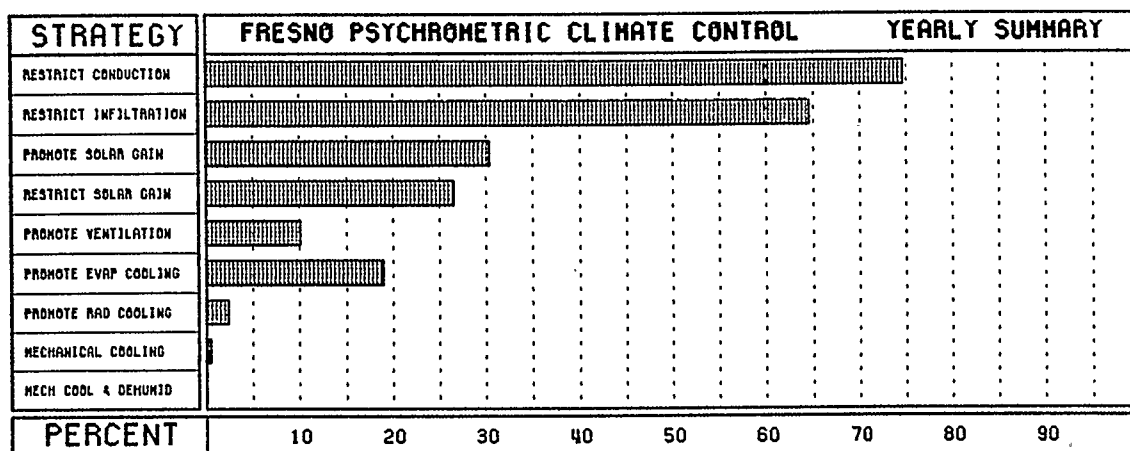
4.12. DECEMBER

The continuous presence of the December climate in the heating zones indicates the importance of conservation for this month. Solar gain is desirable on all surfaces but the only major solar collecting surfaces are the south wall and roof.

The prevailing winds are again from the northwest and southeast directions.

4.13. YEARLY SUMMARY

An inspection of the SCCBAR yearly summary chart reproduced here in Figure 4.8 indicates a measure of the relative importance of each strategy. The domination of the Restrict Conduction and Restrict Infiltration strategies is readily apparent. This can be explained by the fact that these strategies come into play during both the under-heated and over-heated periods. The



(V. ALLISON - 09/85)

Figure 4.8

similar importance of promoting and restricting solar gain indicates that the designer will need to pay special attention to

the design of glazed apertures and their requisite shading devices.

It is seen from this chart that if a building can be designed to be well insulated, free from unwanted infiltration, selective in its solar apertures, allow for cross ventilation and make use of an evaporative cooler then it should keep its occupants comfortable with a minimal reliance on mechanical heating or a compressor type air conditioner. Whether the building can remain comfortable during the winter months without mechanical heating equipment cannot be answered by the analysis presented here. The answer to this question requires more specific information on the nature of the architectural design such as the sizes of its collection area and thermal storage mass.

5. ANALYSIS OF THE SPREADSHEET OUTPUT

In order to keep the number of the spreadsheets to a manageable quantity the following assumptions were made:

- * The 'client' would only consider a direct gain system.
- * No triple glazing or night insulation was to be used.
- * The budget was not to exceed \$3 000 for the conservation and solar features.
- * The buildings dimensions, base case insulation levels and construction costs were fixed at those values entered in the spreadsheets of Section 3.3 and Appendix 8.
- * The 'buildable' insulation levels were equated with the optimum value.
- * The cost to build the walls varied directly with the calculated incremental cost of wall insulation.
- * The number of air changes per hour was set at 1.
- * Solar savings fractions of 0.25 and 0.45 were selected to represent a minor and modest solar building. No major solar building was investigated due to the overheating problems that were demonstrated in the previous sections.

Based on the assumptions listed above, a total of six spreadsheets was produced. The budget limitation of \$3 000 further narrowed the selection to the spreadsheet of Section 3.3 and the first three in Appendix 8. The results of those spreadsheets are summarized here in Figure 5.1.

Direct Gain System	SSF	Passive Solar Area	Total Add-on Cost	Energy Savings	Investment
-----	-----	-----	-----	-----	-----
A1	0.25	10.2 sqm	\$2 106	26.1 GJ/yr	\$81/GJ
B1	0.25	10.2 sqm	\$1 919	25.0 GJ/yr	\$77/GJ
C1	0.25	8.9 sqm	\$1 644	23.7 GJ/yr	\$70/GJ
C1	0.45	19.3 sqm	\$2 584	31.7 GJ/yr	\$82/GJ

Spreadsheet Summary

Figure 5.1

As the total wall area of the house is 80.4 square metres, it is unlikely that system C1 with a solar savings fraction of 0.45 is a good design to pursue since the solar collection area would have to encompass the entire south wall. At this point the designer can reevaluate the characteristics of the reference designs to see which one he would like to develop further. Since all of the designs fall well within the budget the designer could also alter the buildable insulation levels or tightness of the building to further enhance its energy performance. Due to the high summertime insolation levels indicated by the INSPLOT graphs for surfaces with zero tilt (i.e. the flat roof) the designer would be wise to consider increasing its insulation level beyond those indicated by the spreadsheet.

6. LIMITATIONS OF THE ANALYSIS

6.1. THE BUILDING BIOCLIMATIC ANALYSIS MODEL

6.1.1. General Guidelines

As can be seen by an inspection of the SCCPLOT outputs for the winter months, the model does not provide any startling insights for climate control strategies. Insulating, use of tight construction and allowing for some solar gain are the standard methods employed by architects designing for cold climates. In fact, it is generally accepted that when designing for very cold climates, super-insulating and allowing only minimal glazing areas are the best strategies to pursue[20]. It is a moot point whether any of the cooling strategies that the model indicates would be worth pursuing in a design for a northern climate. As ventilation is a 'free' cooling strategy it would not hurt to design it into any building. However, the SOLPATH and INSPLIT outputs might still prove useful in taking advantage of any existing insolation. The INSPLIT output would be especially valuable if the designer were considering the use of active solar collectors for water or space heating as these plots could aid in a performance analysis of the collectors in the climate in question. The WINDROSE plots would be useful in the design of windbreaks and protected entrances. This is, of course, subject

to the limitations previously discussed in Section 1.3.3.

If the SCCPLOT and WINDROSE outputs indicate that little or no wind is available during those times when wind is indicated as a cooling strategy, the designer might consider using landscaping or other natural features to funnel any winds toward the building. This strategy would need to be considered in conjunction with any available winds during the heating season as funneling features might adversely effect the building's conduction and infiltration heat losses.

An inspection of the twelve windroses of Appendix 5 shows that some of the plots have a very ordered appearance. It is suspected that the data that generated these plots was collected by instruments capable of only very coarse measurements. The *CONV2.TMYFRE* database for these months indicated that both the wind speed and direction only took on values in quantum steps. These plots hinder an accurate assessment of the winds as several points can be overlaid, thus hiding both the number of occurrences and time of the occurrence.

6.1.2. Consequences of Water Use

The strategy of promoting evaporative cooling is most effective in a warm, dry region such as the southwestern United States. It also happens that in many of these warm, dry areas water conservation is also a significant problem. In specifying

an evaporative cooling system, the designer should be aware of the immediate and long term implications of the use of such a system. The use of roof sprays or ponds for the cooling of buildings has also been demonstrated as an effective cooling method[21]. The specification of these types of systems might have severe consequences on a limited water supply if their use became widespread.

6.1.3. Human Comfort Models

As previously stated, the reliability of a model depends on the accuracy and completeness of its algorithms. This model's algorithms assigns 'hard edges' to each of the zones of the building bioclimatic chart. In the real world the boundaries of these zones are composed of 'fuzzy' lines as people are not likely to agree on the very subjective question of their respective thermal comfort. It must therefore be realized that any one model cannot please all of the people all of the time.

It was indicated in Olgyay[22] that man's comfort zone shifts between summer and winter as a function of the typical clo values of seasonal clothing. Hence, Olgyay's bioclimatic chart had two comfort zones: one for summer and one for winter. Olgyay's chart was further limited in its application to those people residing in "moderate climate zones". This raises the question of man's acclimatization to his region as well as what he expects from a thermally comfortable building. It was reported in

Olgyay[23] that there are significant differences between British and American residents' comfort zones. The present model represents only the Watson and Labs comfort zone; what cross-section of the population provided the data for its boundaries was not indicated. It is probably a reasonable assumption that it, like Olgyay's, applies to the inhabitants of a moderate climate. If a designer was working in a region whose inhabitants had a well-documented comfort zone, the boundaries of the zones in the building bioclimatic chart could be altered to suit the local population. Whether this would have a significant effect on the climate control strategies cannot be answered at this time.

The comfort zone is also defined on the basis of an assumed clothing insulation level (typically, 0.6 clo). Hence the comfort zone could be extended into both colder and warmer temperature ranges with the addition or removal of clothing. This type of measure assumes that the addition or removal of clothing is both socially and functionally acceptable for the location and tasks at hand.

Finally, the comfort zone is also defined on the basis of an assumed sedentary activity level. If the architect was designing a space for higher activity levels he would be wise to consider altering the boundaries of the comfort zone towards cooler temperatures. The changing of the zone boundaries would require

the alteration of data in files *BCCDATA* AND *BCPDATA*. See Appendix 11 for a discussion of factors effecting changes to the comfort zone.

6.2. BIOCLIMATIC ANALYSIS VERSUS COMPUTER SIMULATIONS

Energy analysis simulation programmes like DOE-2 are used by some designers to predict the performance of their buildings. These programmes begin with the same climate data base as the model of this research and provide detailed evaluations of a building's performance. This model differs in that the designer would employ it during the preliminary design process rather than to evaluate an already designed building. Other than entering the surface orientation data required by the INSPLIT programme, the user need not have made any design decisions (such as wall constructions or the sizing of glazing and thermal masses). Hence, this model is more of a preliminary design tool rather than a performance evaluation device. It is also possible to produce the complete output of the model along with several analysis spreadsheets in an afternoon compared with the more lengthy and complex process of writing a DOE-2 programme.

At this time the model runs only on Arizona State University's mainframe IBM computer. However, it would not be a difficult task to rewrite the programmes to run on a personal computer and have their output generated on the plotter of an architect's

in-house computer aided design system. The SPSS-X crosstabulation could be written as a simple sorting routine if the user chose not to buy the personal computer SPSS-X software package.

6.3. HEATING AND OVER-HEATING ANALYSIS

In the model's present state, a method to evaluate both the heating and over-heating potential of the insolation is lacking. Although this model gives an accurate accounting of the total insolation incident on any surface it does not allow the designer to determine whether the insolation is sufficient to heat a building during the winter months. Nor does it answer the question of whether the intensity of the insolation is sufficient to cause serious overheating problems. This question cannot usually be answered in the preliminary design stage as the design details have yet to be specified. It is during the design development phase that the architect could consider the use of an energy analysis programme such as DOE-2 or one of the simpler software packages that can run on a micro computer. The use of one of these programmes at this stage would aid in the design of fixed shading devices as the architect could vary their size until an optimal energy performance was achieved. The development and analysis of such a design is beyond the scope of this report.

6.4. THE CONSERVATION / SOLAR SPREADSHEET

The spreadsheet analysis tool has some inherent limitations and makes some assumptions about the skill of the designer. Anyone using the spreadsheet should have some familiarity with the principles of passive design. Even the best of intentions will not prevent a poorly designed solar building from serious over-heating if the solar apertures are oversized, shading devices are not properly designed or sufficient thermal mass is not provided. There are several texts[24] [25] [26] that describe in detail the principles associated with these factors; further references can be found in the Passive Solar Design Handbook (Los Alamos Laboratories, 1984).

The assumption of constant construction costs per RSI value is not a very good approximation. However, this assumption does " ... characterize the general trend and therefore is useful in locating the 'region' of the optimum" insulation levels[27].

The method presented in the Passive Solar Design Handbook (Los Alamos Laboratories, 1984) for the estimation of costs for decreasing the number of air changes per hour are limited to one specific example. These costs are generally difficult to determine as little pricing information is available.

The use of the spreadsheet is further limited to the reference

designs presented in the Passive Solar Design Handbook (Los Alamos Laboratories, 1984). Although these designs include 9 direct gain, 28 sunspace, 15 water wall and 42 trombe wall options they do not consider other passive techniques such as convective loops or rockbed storage.

As the spreadsheet was written with the LOTUS 1-2-3 software package the user must have access to this system. Of course, the spreadsheet could easily be written to work with any other commercially available spreadsheet programmes. The user is required to have only limited knowledge of the use of these programmes to perform the analysis.

Appendix 12 discusses the limitations of the selection of the initial solar savings fraction.

7. CONCLUSIONS

7.1. PASSIVE DESIGN GUIDELINES FOR FRESNO

The points in Appendix 9 summarize the monthly evaluations of Sections 4.1 through 4.12 and Section 4.13. Reference is also made to the model's outputs in Appendices 1 through 8.

The following design guidelines summarize the monthly evaluations of Appendix 9. The annual guidelines were selected from the union of each of the monthly guidelines. Hence, as 'Insulate' appears in each month, it appears in the yearly summary.

- * Insulate.
- * Tight construction.
- * Promote solar gain on south November - March.
- * Promote solar gain on east; some controls June - August.
- * Promote solar gain on west November - March.
- * Promote solar gain on roof November - March.
- * Protect from northwest - southeast winds December - March.
- * Low mass eastern construction.
- * Allow for cross-ventilation on north and/or west sides.
- * Exterior shading devices on south and west.
- * Adjustable shading devices on west.
- * Roof venting.
- * Light colored roof surface.
- * Mass type construction on west.
- * Specify evaporative cooling system.
- * Interior mass for nighttime ventilation.

The spreadsheet summary of Figure 5.1 indicates that an economically based decision would be in favor of reference design

C1 with a solar savings fraction of 0.25. This decision can be further justified on the basis of the relatively small spread in energy savings and the minimum-sized passive solar area. Keeping the south facing glazing to a minimum size reduces the possibility of overheating during the summer period. As the proposed budget for the conservation and solar features was set at \$3 000, it is recommended that the difference between this figure and the calculated add-on cost of \$1 664 be used to increase the roof and wall insulation levels and, if possible, reduce the number of air changes per hour to less than one.

A further spreadsheet analysis indicated that it would be possible to increase the roof insulation from RSI 2.6 to RSI 7.0, the wall insulation from RSI 2.0 to RSI 3.5 and to reduce the number of air changes to 0.5 per hour and still remain within the \$3 000 budget. These figures are, of course, subject to the costing limitations discussed in Section 6.4. This spreadsheet is included in Appendix 8.

Two consequences of the decision to employ a direct gain design are its requisite thermal mass and south facing glazing. The spreadsheet analysis indicated that reference design C1 now requires a mass area of 31.3 square metres and a glazing area of 5.2 square metres. The thermal storage capacity of the reference designs corresponds to that of high density masonry or concrete. The mass in the reference designs is located on the floors and

north walls of the south facing rooms.

As a concluding remark it should be pointed out that it was not the intent of this report to indicate how these design recommendations could be implemented in a building but rather to suggest what features and strategies would prove beneficial based on the output of the model and spreadsheet.

7.2. SUGGESTIONS FOR FURTHER RESEARCH

If the Building Bioclimatic Analysis Model were to become a popular design tool, the need for its introduction into the architect's office is apparent. It is therefore suggested that a logical continuation of this project be to continue the work on a mainframe computer and compile a text of the model's outputs for the presently available climate databases. The shortcoming of this approach is the potential tome of output charts that would be generated by applying the model to all the available climate databases.

Alternatively, one could adapt the programmes to run on a micro computer. This work would be based on the assumption that the requisite climate databases are available to users on floppy disk and that architects have an in-house micro computer and plotting device.

As was indicated in Section 6.3 the present model cannot evaluate either the heating or over-heating potential of any incident insolation. It would be a worthwhile project to assess the feasibility of using the information from the INSPLIT output (or a database generated by a similar programme) to size solar apertures and thermal masses.

The design of shading devices with predictable shading patterns is a time consuming process. An interactive graphic programme that would allow the architect to design and see the effect of a proposal at any latitude for any given day would be a useful tool. A project of this nature could continue along the lines of the previous suggestion and incorporate shading into the energy calculations.

Another avenue of exploration would be the development of simplified algorithms for cooling load calculations. This would allow the designer to evaluate insulation levels on the basis of cooling degree days as well as heating degree days.

7.3. SUMMARY REMARKS

The Building Bioclimatic Analysis Model is seen to be a powerful new climate analysis tool for architectural applications. Its principle advantage over other climate analysis methods is its use of hourly TMY data instead of the

averaged data that is used by other methods. The hourly TMY data provides the model with the best possible climate database. The use of this high-resolution climate database necessitated the development of computer methods to handle the otherwise humanly impossible hourly analysis. The computerization of the bioclimatic analysis resulted in the ability to produce the complete output of the model in a few hours which offers a tremendous time savings over any manual methods.

It was also demonstrated that the development of architectural design guidelines for a given climate is a simple task for the architect to pursue once in possession of the model's outputs.

The interactive conservation/solar spreadsheet provides the architect with the ability to assess quickly and easily the costing and energy conserving implications of various passive design strategies. The simplicity of this tool encourages the designer to explore several different design concepts during the preliminary design stage.

Neither the Building Bioclimatic Analysis Model nor the Balancing Conservation and Solar Spreadsheet impose any design constraints on the architect. The tools indicate which design strategies would prove useful in the design of an energy conscious building. It is left to the architect's ingenuity and creativity to develop the design guidelines into a piece of architecture.

8. FOOTNOTES

[1]

Victor Olgyay and Aladar Olgyay. Design With Climate. Bioclimatic Approach to Architectural Regionalism. Princeton: Princeton University Press, 1963. p. 24.

[2]

J. Douglas Balcomb, Robert W. Jones, Claudia E. Kosiewicz, Gloria S. Lazarus, Robert D. McFarland and William O. Wray. Passive Solar Design Handbook. Volume III. New York: American Solar Energy Society, Inc., 1982. p. v.

[3]

Victor Olgyay and Aladar Olgyay. Design With Climate. Bioclimatic Approach to Architectural Regionalism. Princeton: Princeton University Press, 1963. p. 24.

[4]

Los Alamos Laboratories. Passive Solar Design Handbook. New York: Van Nostrand Reinhold Co., 1984. pp. 138, 731.

[5]

Ibid. pp. 139, 731.

[6]

Ibid. pp. 139, 731.

[7]

Ibid. pp. 101, 139, 733.

[8]

Victor Olgyay and Aladar Olgyay. Design With Climate. Bioclimatic Approach to Architectural Regionalism. Princeton: Princeton University Press, 1963. p. 31.

[9]

M. Milne and B. Givoni. "Architectural Design Based on Climate," in Energy Conservation Through Building Design. ed. D. Watson. New York: Architectural Record Books / McGraw - Hill Book Co., 1979. p. 97.

[10]

Ibid. p. 97.

[11]

Ibid. p. 109.

[12]

J. Douglas Balcomb. "Conservation and Solar: Working Together," in Proceedings of the Fifth National Passive Solar Conference of the American Section of the ISES, Vol. 5.1, 1980.

[13]

Los Alamos Laboratories. Passive Solar Design Handbook. New York: Van Nostrand Reinhold Co., 1984. p. 143.

[14]

Energy Research Development Group. Energy Efficient Housing: A Prairie Approach. Regina: University of Saskatchewan Press, 1980.

[15]

I. J. Hall, R. R. Prairie, H. E. Anderson and E. C. Boes. Generation of Typical Meteorological Years for 26 SOLMET Stations. (Albuquerque, NM: Sandia Laboratories), p. 1.

[16]

ASHRAE Task Group on Energy Requirements. Procedure for Determining Heating and Cooling Loads for Computerizing Energy Calculations. Algorithms for Building Heat Transfer Subroutines. (Atlanta: ASHRAE 1975), pp. 165 - 167.

[17]

SPSS-X. User's Guide. New York: McGraw-Hill Book Co., 1983.

[18]

ASHRAE Applications Handbook 1982. "Solar Energy Utilization." (Atlanta: ASHRAE, 1982), pp. 57.1 - 57.11.

[19]

Lotus 1-2-3 User's Manual. Cambridge, MA: Lotus Development Corporation, 1983.

[20]

Energy Research Development Group. Energy Efficient Housing: A Prairie Approach. Regina: University of Saskatchewan Press, 1980.

[21]

Donald Watson and K. Labs. Climatic Design. Energy Efficient Principles and Practices. New York: McGraw-Hill Book Co., 1983. pp. 65 - 70, 169 - 170.

[22]

Victor Olgyay and Aladar Olgyay. Design With Climate. Bioclimatic Approach to Architectural Regionalism. Princeton: Princeton University Press, 1963. p. 18.

[23]

Ibid. p. 17.

[24]

Edward Mazria. The Passive Solar Energy Book. Emmaus, PA: Rodale Press, 1979.

[25]

Total Environmental Action, Inc. The Thermal Mass Pattern Book. Harrisville, NH: T.E.A Inc., 1979.

[26]

Aladar Olgyay and Victor Olgyay. Solar Control and Shading Devices. Princeton: Princeton University Press, 1967.

[27]

Los Alamos Laboratories. Passive Solar Design Handbook. New York: Van Nostrand Reinhold Co., 1984. p. 147.

9. BIBLIOGRAPHY

ANSI/ASHRAE STD 55-1981. "Thermal Environmental Conditions for Human Occupancy." New York: ASHRAE, 1981.

ASHRAE Handbook. 1982 Applications. "Solar Energy Utilization." Atlanta: ASHRAE, 1982, pp. 57.1 - 57.11.

ASHRAE Handbook. 1985 Fundamentals. "Physiological Principles for Comfort and Health." Atlanta: ASHRAE, 1985, pp. 8.1 - 8.32.

ASHRAE Task Group on Energy Requirements. Procedure for Determining Heating and Cooling Loads for Computerizing Energy Calculations. Algorithms for Building Heat Transfer Subroutines, Atlanta: ASHRAE, 1975.

Arens, E., R. Gonzalez, L. Berglund, P. McNall and L. Zeren. "A New Bioclimatic Chart For Passive Solar Design." Proceedings of the Fifth National Passive Solar Conference, Vol. 5.1, (1980), p. 1202.

Baltas, P., M. Tortoreli and P. Russel. "Evaluation of Power Output for Fixed and Step Tracking Photovoltaic Arrays." Unpublished paper. Electrical and Computer Engineering, Arizona State University. 1985.

Balcomb, J. Douglas. "Conservation and Solar: Working Together." Proceedings of the Fifth National Passive Solar Conference of the American Section of the ISES. Vol. 5.1, (1980).

Balcomb, J. Douglas, Robert W. Jones, Claudia E. Kosiewicz, Gloria S. Lazarus, Robert D. McFarland and William O. Wray. Passive Solar Design Handbook. Volume III. New York: American Solar Energy Society, Inc., 1982.

de Los Rios, M. "A Bioclimatic Analysis System for Architectural Applications. Graphic Tools and Methods." Unpublished paper. College of Architecture and Environmental Design, Arizona State University. 1984.

Energy Research Development Group. Energy Efficient Housing: A Prairie Approach. Regina: University of Saskatchewan Press, 1980.

Fanger, P. O. Thermal Comfort. Analysis and Applications in Environmental Engineering, New York: McGraw-Hill Book Company, 1972.

- Givoni, B. Man, Climate and Architecture, New York: Van Nostrand Reinhold Co., 1969.
- Gonzalez, R. R. "Experimental Analysis of Thermal Acceptability", in Thermal Analysis - Human Comfort - Indoor Environments. NBS Special Publication 491. (U.S. GPO SN 003-003-01849-0). 1977. pp. 131 - 151.
- Green, N. D., programme author. DAYRAD, Arizona State University: College of Architecture and Environmental Design, Computer Aided Design Lab, 1981.
- Hall, I. J., R. R. Prairie, H. E. Anderson and E. C. Boes. Generation of Typical Meteorological Years for 26 SOLMET Stations. Albuquerque: Sandia Laboratories, 1981.
- Klucher, T. M. "Evaluation of Models to Predict Insolation on Tilted Surfaces." Solar Energy. Vol. 23 (1979), p. 111.
- Los Alamos Laboratories. Passive Solar Design Handbook. New York: Van Nostrand Reinhold Co., 1984.
- Lotus Development Corporation. Lotus 1-2-3 User's Manual. Cambridge, MA. 1983.
- Mazria, Edward. The Passive Solar Energy Book. Emmaus, PA: Rodale Press, 1979.
- Milne, M. and B. Givoni. "Architectural Design Based on Climate," in Energy Conservation Through Building Design. ed. D. Watson. New York: Architectural Record Books / McGraw-Hill Book Co., 1979.
- National Climatic Center. "Typical Meteorological Year User's Manual. TD-9734. Hourly Solar Radiation - Surface Meteorological Observations." Asheville, NC, 1981.
- Olgyay, A. and V. Olgyay, Solar Control and Shading Devices, Princeton: Princeton University Press, 1957.
- Olgyay, V. and A. Olgyay, Design With Climate. Bioclimatic Approach to Architectural Regionalism, Princeton: Princeton University Press, 1963.
- Precision Visuals. DI - 3000 User's Guide. Colorado: 1982.
- SPSS-X. User's Guide. New York: McGraw-Hill Book Co. 1983.

Total Environmental Action, Inc. The Thermal Mass Pattern Book.
Harrisville, NH: T.E.A. Inc., 1979.

Turner, J., programme author. PSIO, Arizona State
University: College of Architecture and Environmental
Design, Computer Aided Design Lab.

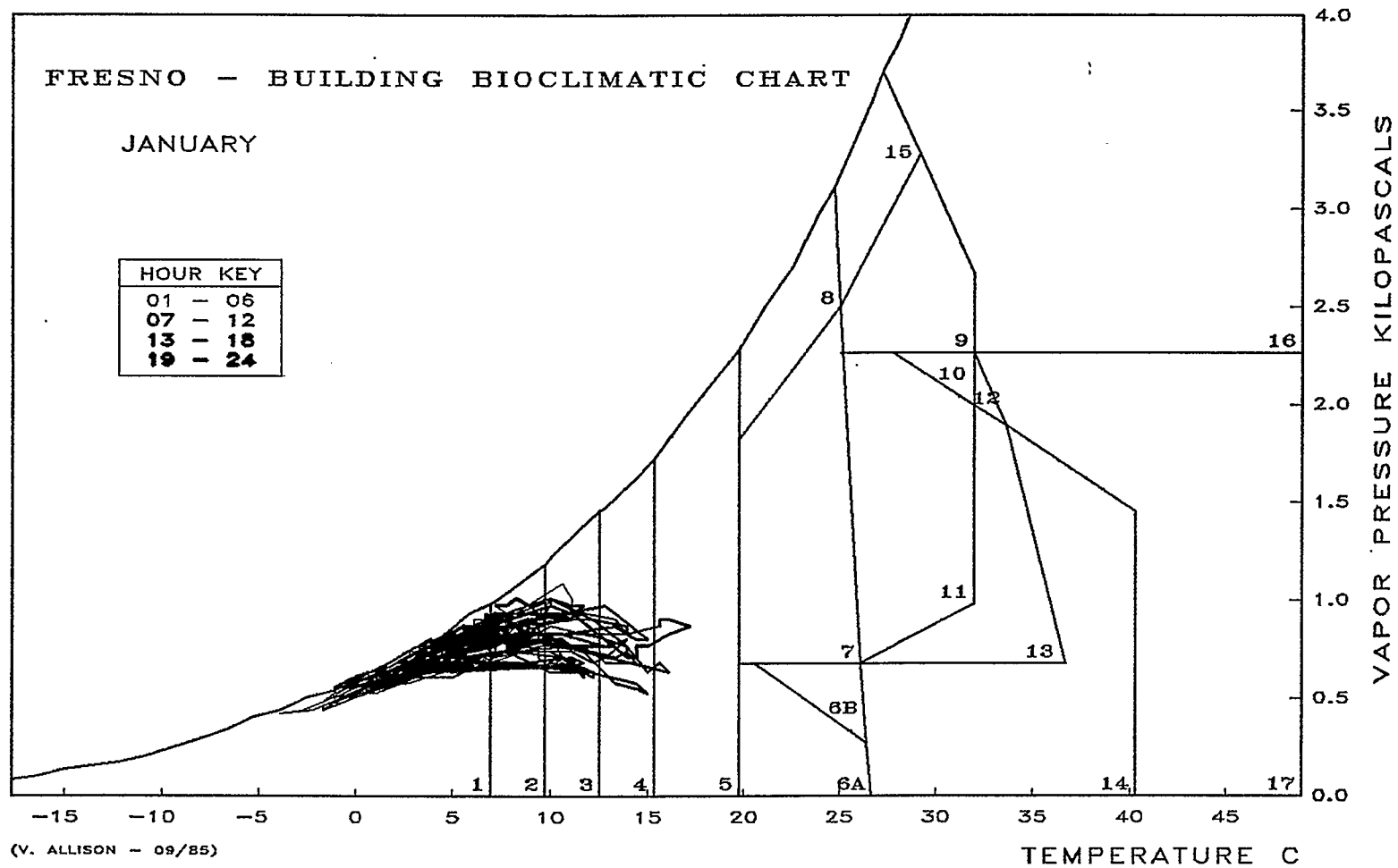
Van Wyk, C., programme author: TMYREST (Version 1.0),
Arizona State University: College of Architecture and
Environmental Design.

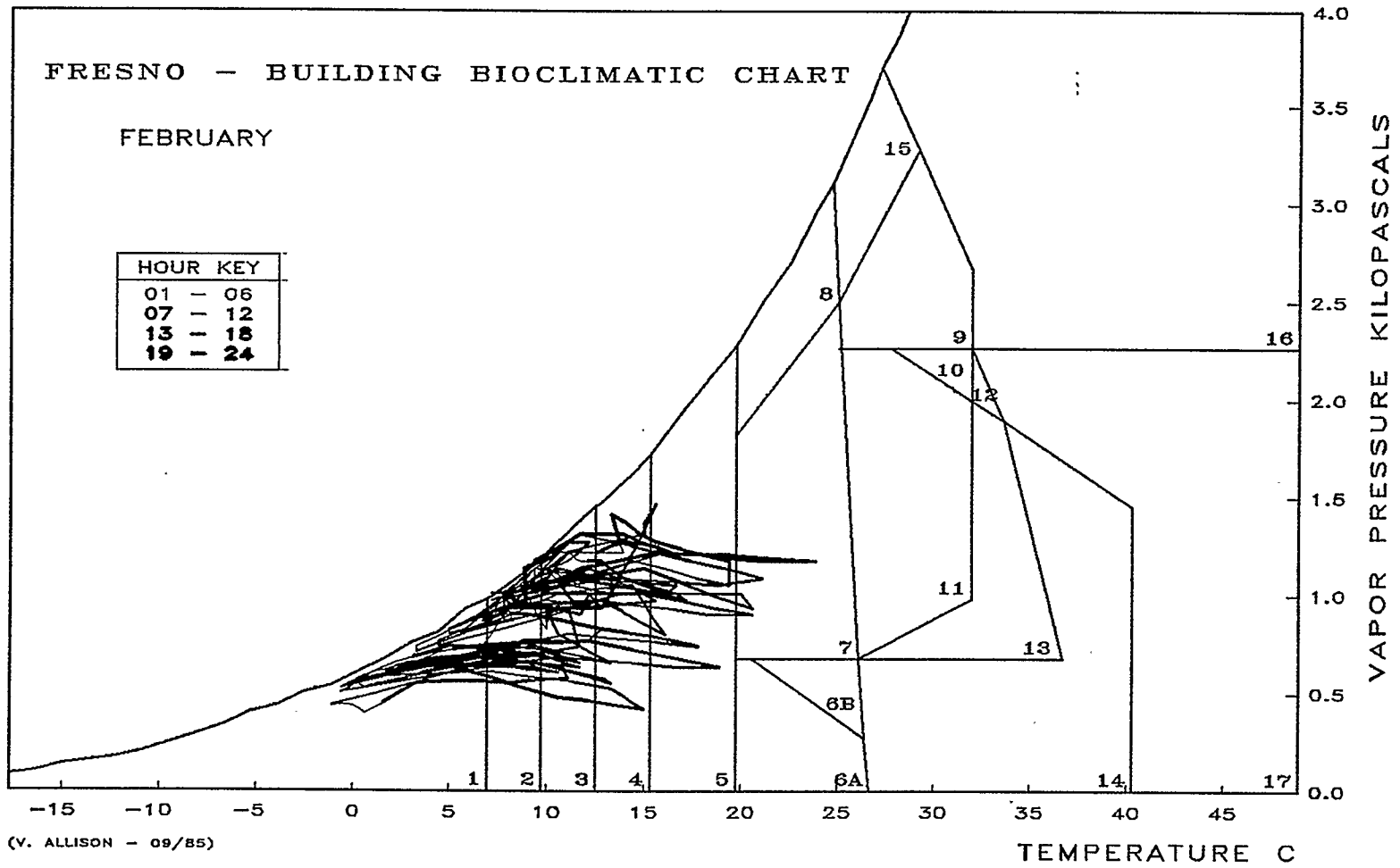
Van Wyk, C., programme author. TMYCONV (Version 1.0),
Arizona State University: College of Architecture and
Environmental Design.

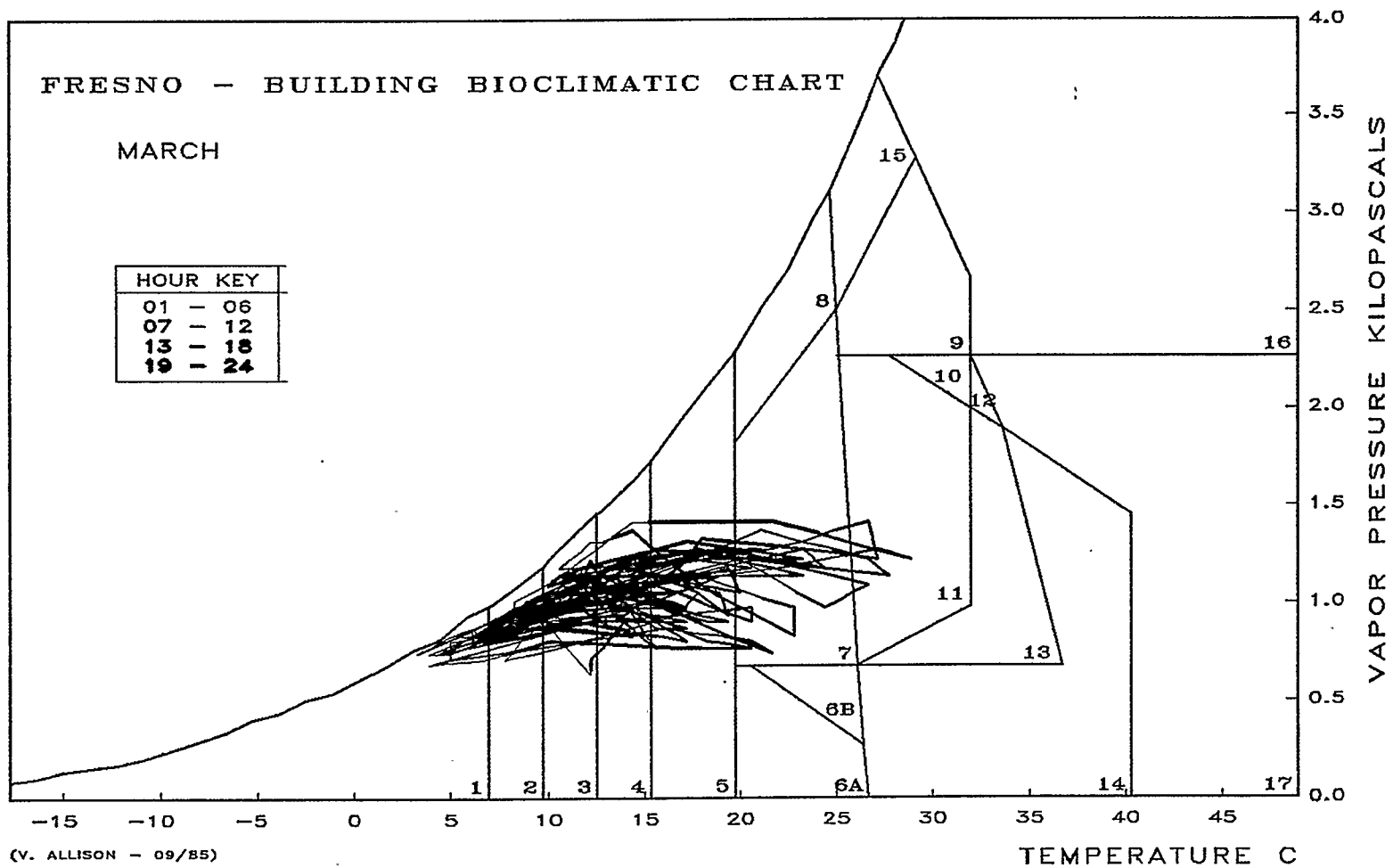
Van Wyk, C. "Bioclimatic Analysis and Preliminary Building
Design." Proceedings of the Tenth National Passive Solar
Conference of the American Section of the ISES.
October 15-18, 1985.

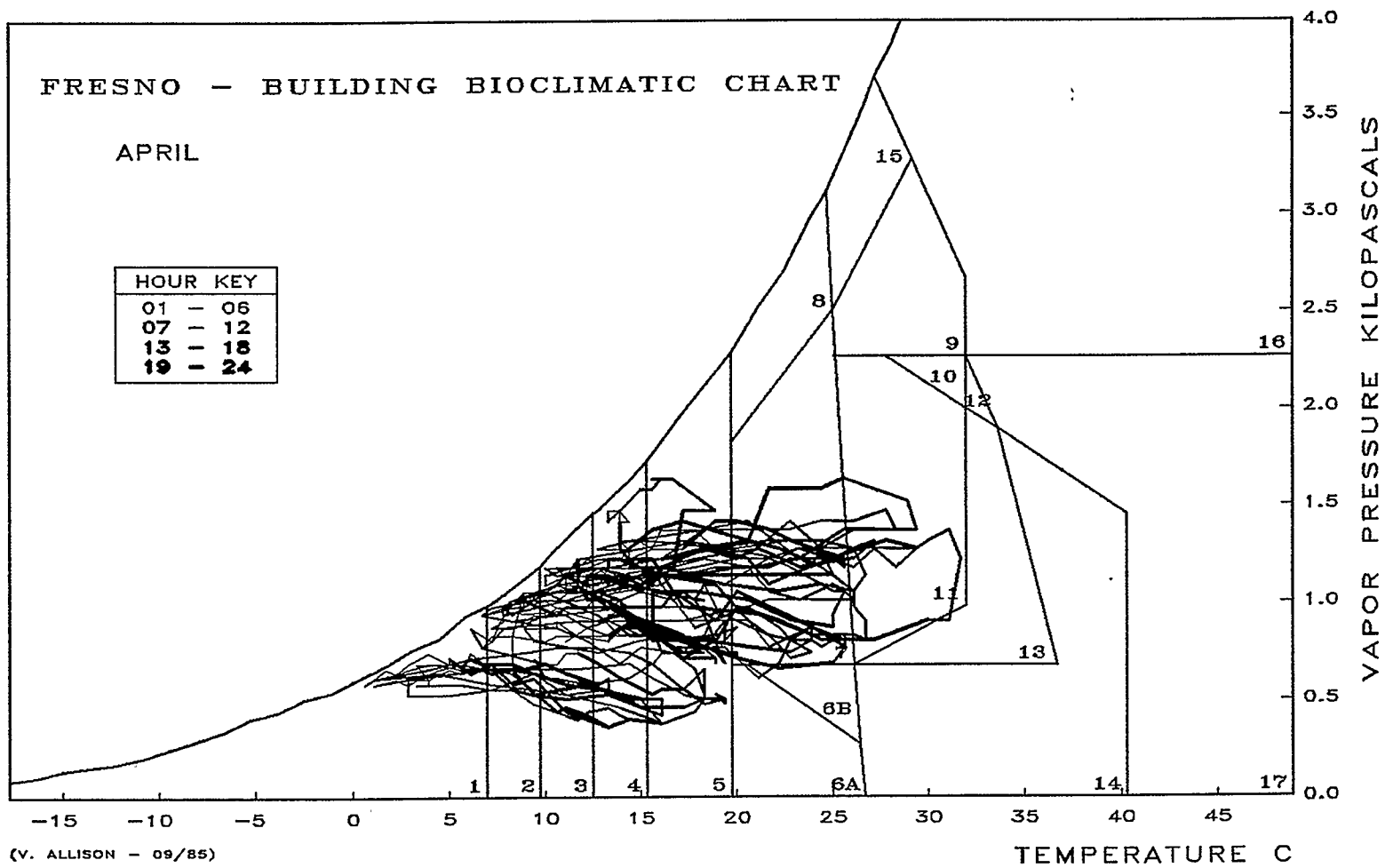
Watson, D. and K. Labs, Climatic Design. Energy Efficient
Principles and Practices, New York: McGraw-Hill Book
Co., 1983.

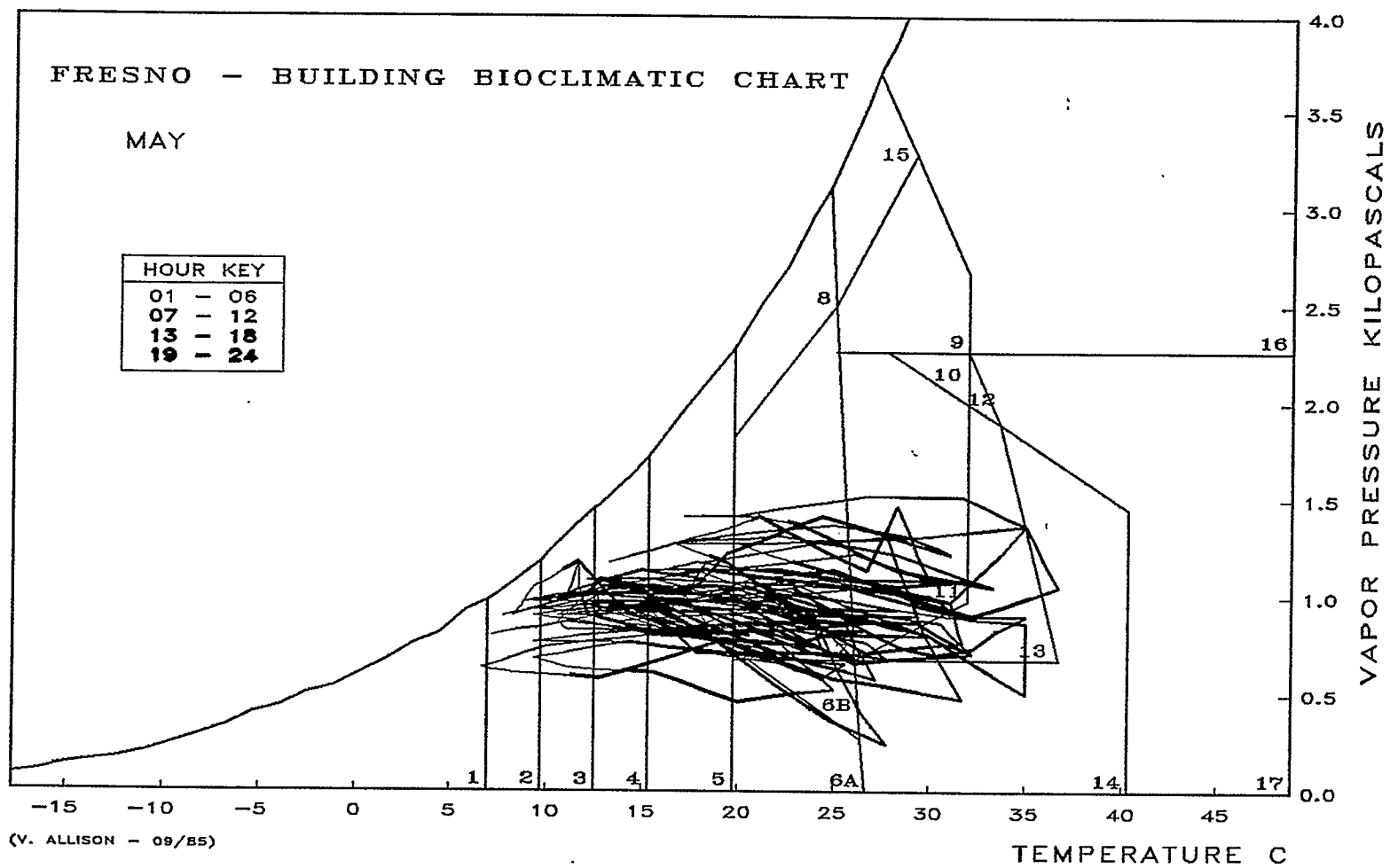
10. APPENDIX 1 - PSYCHART OUTPUT

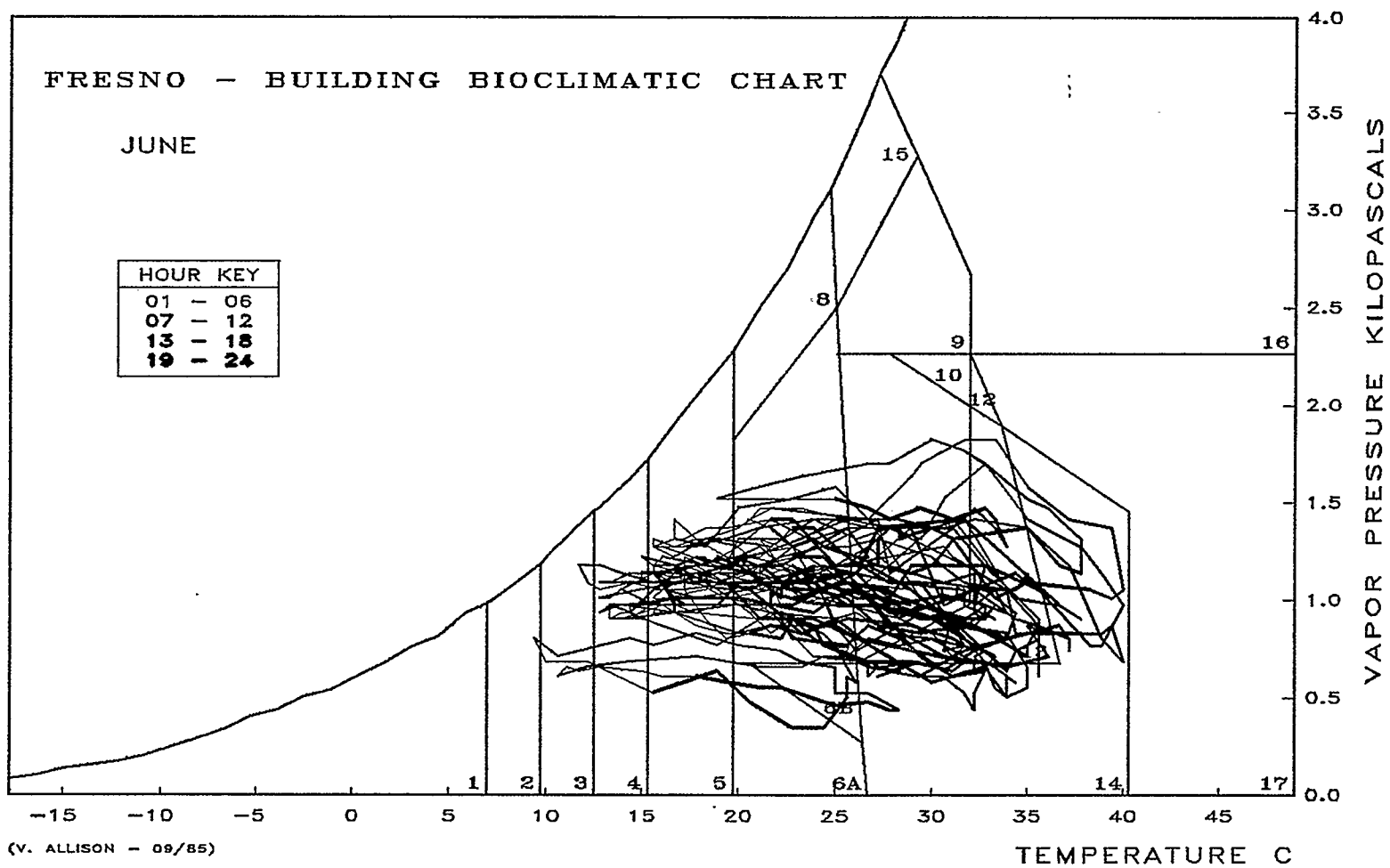


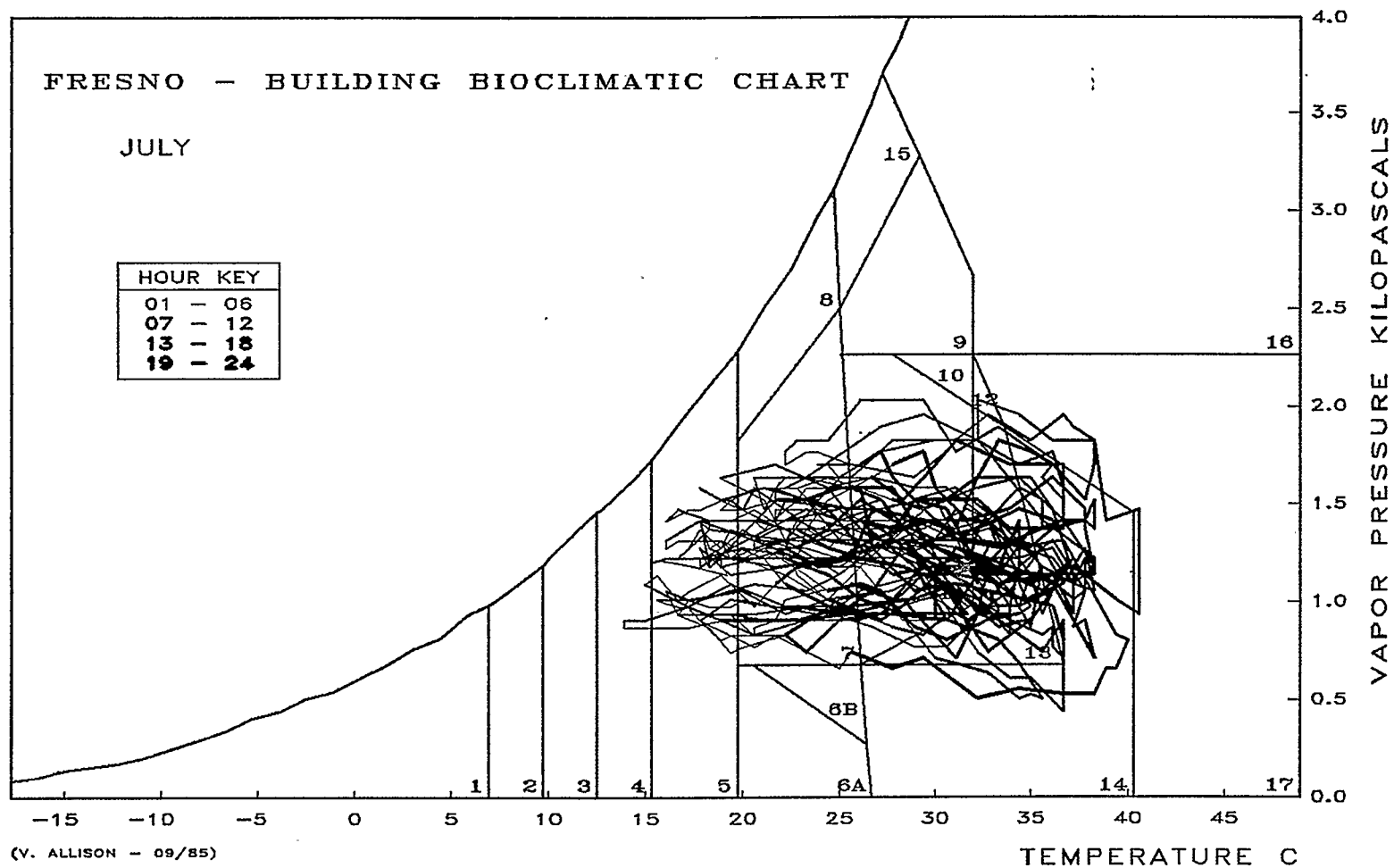


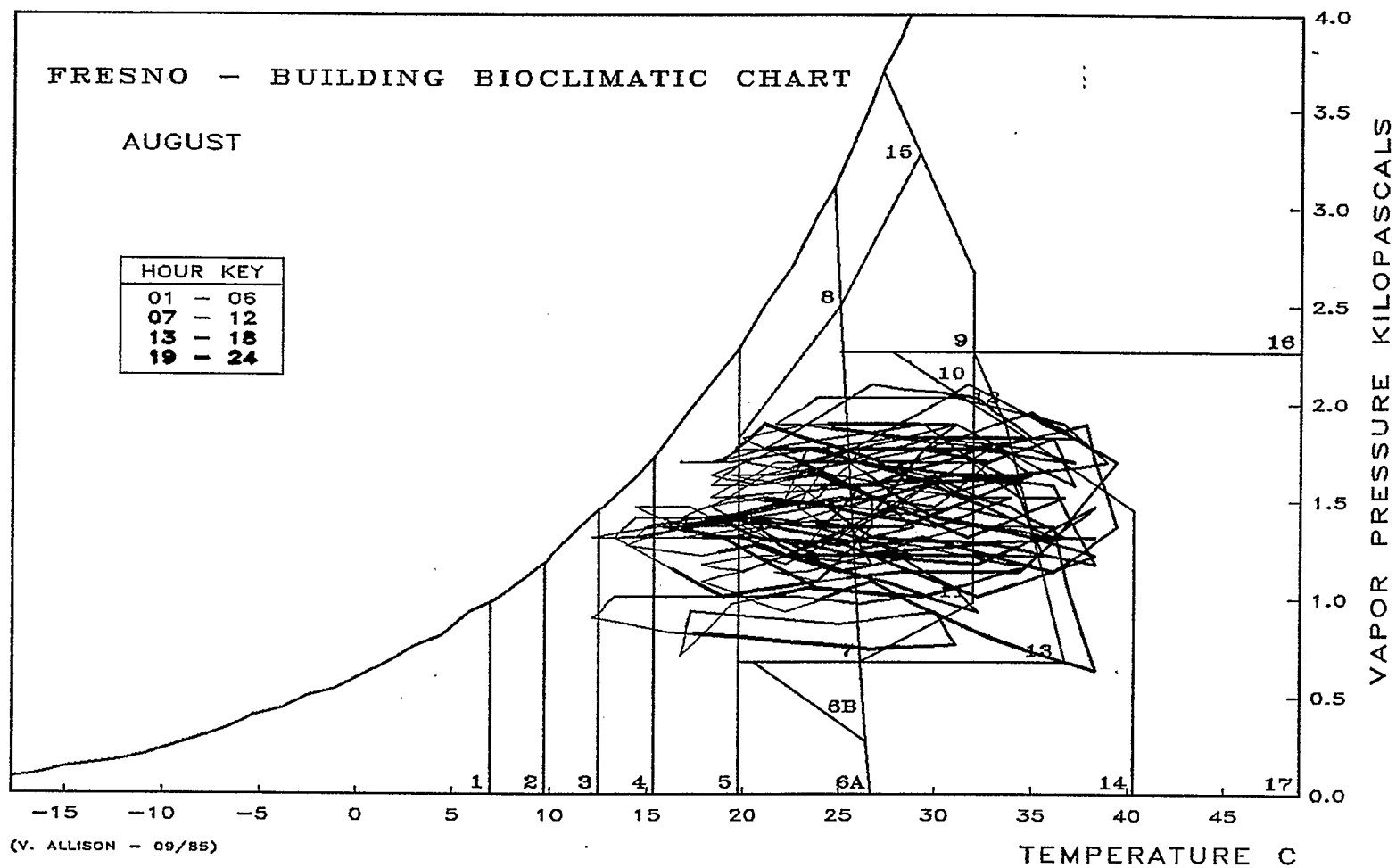


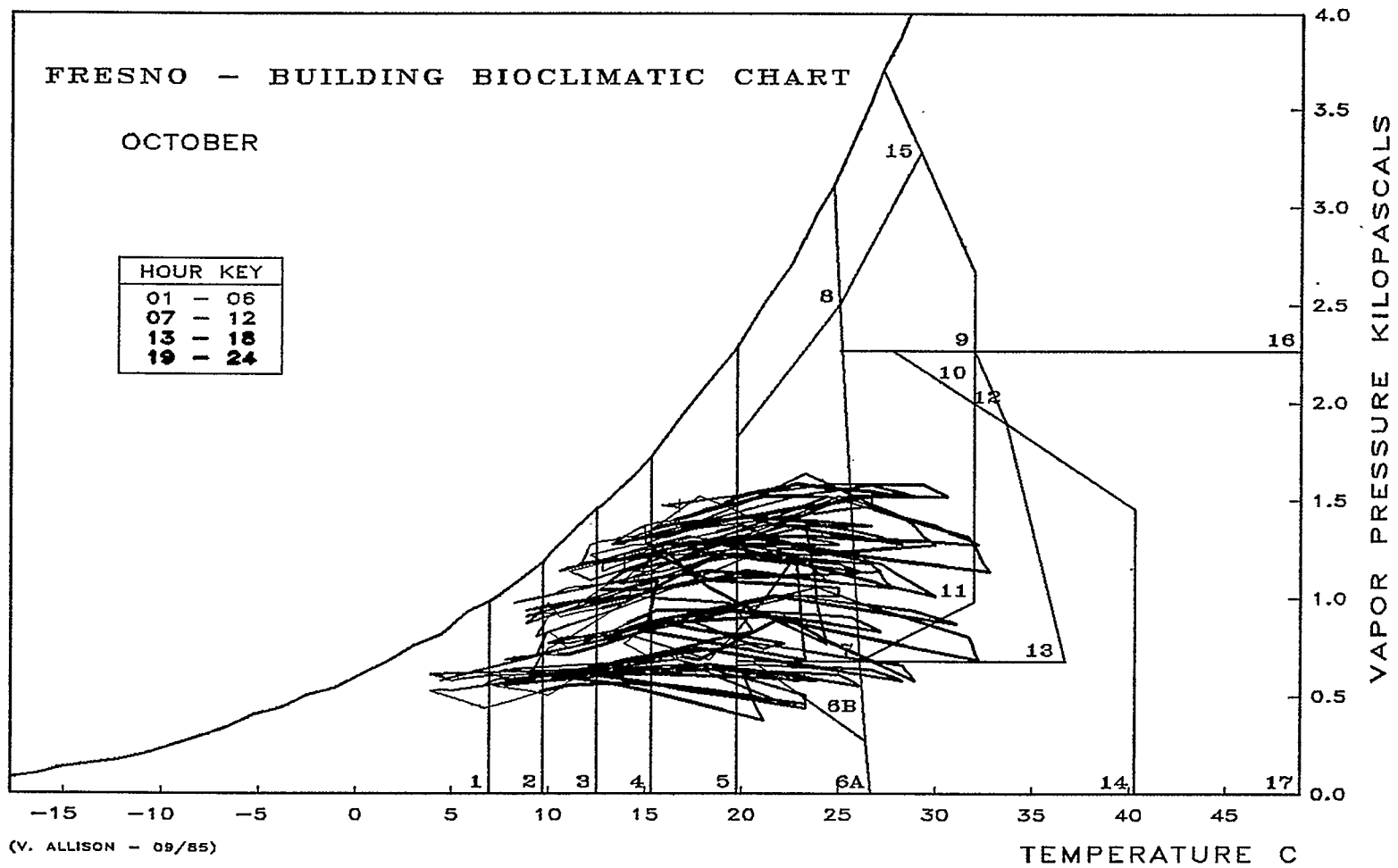








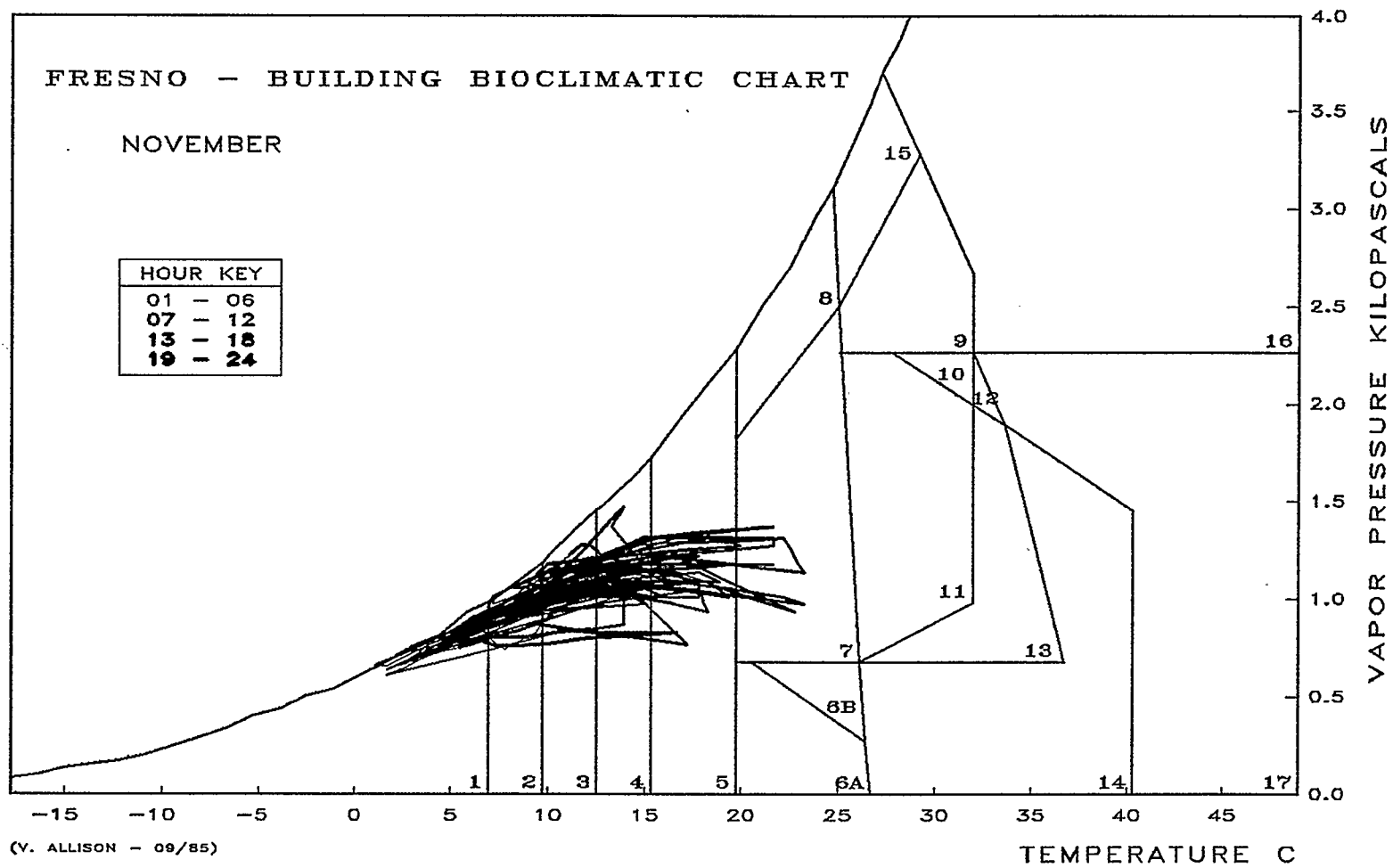


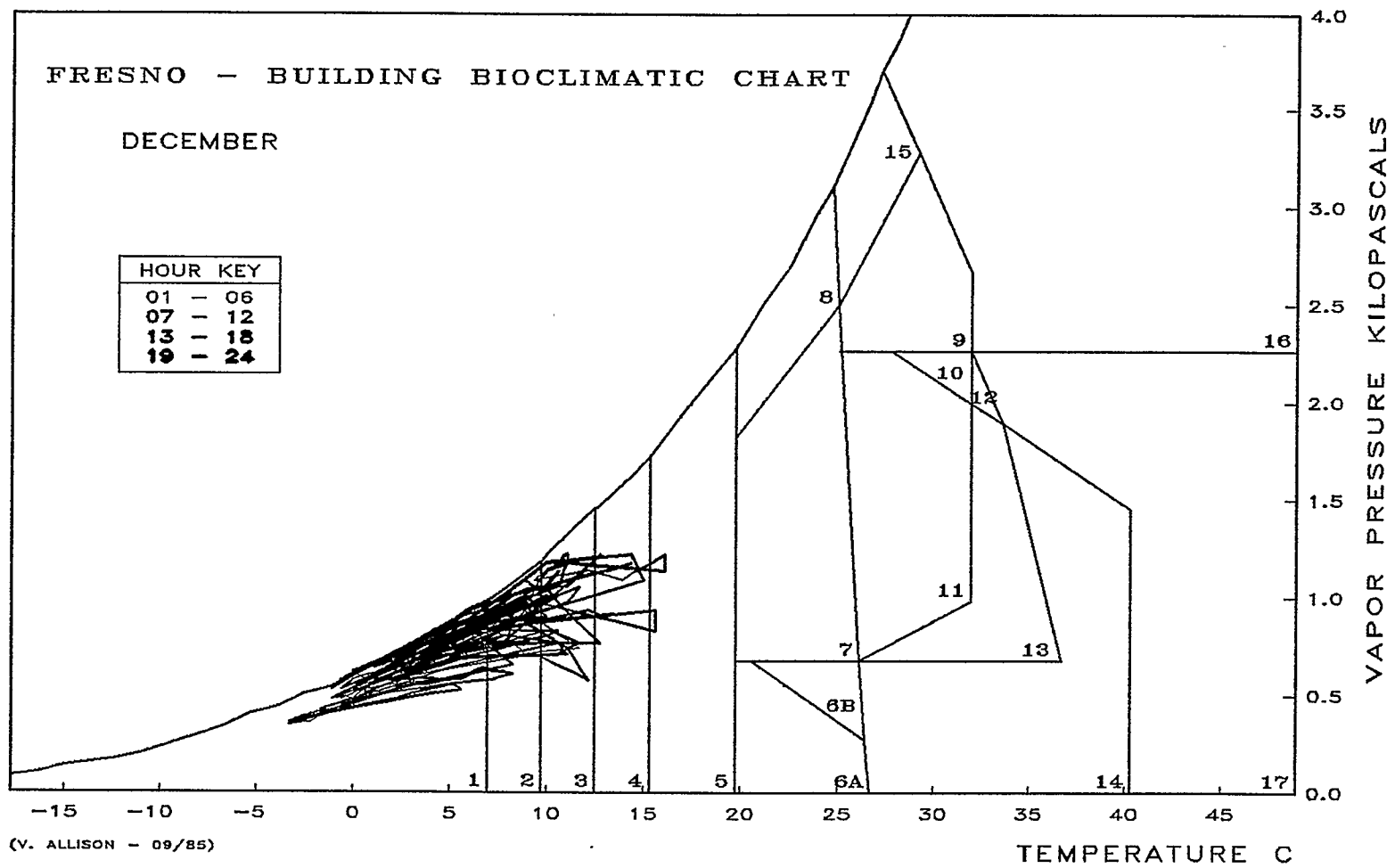


FRESNO - BUILDING BIOCLIMATIC CHART

NOVEMBER

HOUR KEY	
01 - 06	
07 - 12	
13 - 18	
19 - 24	





11. APPENDIX 2 - OCCURPLT OUTPUT

[illegible]

[illegible]

STRATEGY		FRESNO - BUILDING BIOCLIMATIC ANALYSIS														APRIL									
ZONE 01 HEATING																									
ZONE 02 HEATING																									
ZONE 03 HEATING																									
ZONE 04 HEATING																									
ZONE 05 HEATING																									
ZONE 6A HUMIDIFY																									
ZONE 6B HUMIDIFY																									
ZONE 07 COMFORT																									
ZONE 11 COOLING																									
ZONE 13 COOLING																									
TIME		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - BUILDING BIOCLIMATIC ANALYSIS MAY																							
ZONE 01 HEATING																								
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ZONE 04 HEATING																								
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ZONE 6A HUMIDIFY																								
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TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - BUILDING BIOCLIMATIC ANALYSIS																							
	JUNE																							
ZONE 02 HEATING																								
ZONE 03 HEATING																								
ZONE 04 HEATING																								
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ZONE 6A HUMIDIFY																								
ZONE 6B HUMIDIFY																								
ZONE 07 COMFORT																								
ZONE 11 COOLING																								
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ZONE 14 HUM-COOL																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

[illegible]

STRATEGY		FRESNO - BUILDING BIOCLIMATIC ANALYSIS																AUGUST								
ZONE 03 HEATING																										
ZONE 04 HEATING																										
ZONE 05 HEATING																										
ZONE 07 COMFORT																										
ZONE 10 COOLING																										
ZONE 11 COOLING																										
ZONE 12 COOLING																										
ZONE 13 COOLING																										
ZONE 14 HUM-COOL																										
ZONE 17 COOLING																										
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		

STRATEGY	FRESNO - BUILDING BIOCLIMATIC ANALYSIS																							SEPTEMBER
ZONE 01 HEATING																								
ZONE 02 HEATING																								
ZONE 03 HEATING																								
ZONE 04 HEATING																								
ZONE 05 HEATING																								
ZONE 6A HUMIDIFY																								
ZONE 6B HUMIDIFY																								
ZONE 07 COMFORT																								
ZONE 11 COOLING																								
ZONE 13 COOLING																								
ZONE 14 HUM-COOL																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - BUILDING BIOCLIMATIC ANALYSIS																							
	OCTOBER																							
ZONE 01 HEATING																								
ZONE 02 HEATING																								
ZONE 03 HEATING																								
ZONE 04 HEATING																								
ZONE 05 HEATING																								
ZONE 6A HUMIDIFY																								
ZONE 6B HUMIDIFY																								
ZONE 07 COMFORT																								
ZONE 11 COOLING																								
ZONE 13 COOLING																								
ZONE 14 HUM-COOL																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - BUILDING BIOCLIMATIC ANALYSIS																							NOVEMBER
ZONE 01 HEATING																								
ZONE 02 HEATING																								
ZONE 03 HEATING																								
ZONE 04 HEATING																								
ZONE 05 HEATING																								
ZONE 07 COMFORT																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - BUILDING BIOCLIMATIC ANALYSIS																							DECEMBER
ZONE 01 HEATING																								
ZONE 02 HEATING																								
ZONE 03 HEATING																								
ZONE 04 HEATING																								
ZONE 05 HEATING																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

12. APPENDIX 3 - SCCPLOT OUTPUT

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL																							
	JANUARY																							
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL																FEBRUARY							
RESTRICT CONDUCTION	[Pattern: Shaded cells from column 1 to 16, and column 18 to 24]																							
RESTRICT INFILTRATION	[Pattern: Shaded cells from column 1 to 16, and column 18 to 24]																							
PROMOTE SOLAR GAIN	[Pattern: Shaded cells from column 7 to 16]																							
RESTRICT SOLAR GAIN	[Pattern: Shaded cells from column 13 to 16]																							
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL																							MARCH
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL APRIL																							
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL MAY																							
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL JUNE																							
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL JULY																							
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL AUGUST																							
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

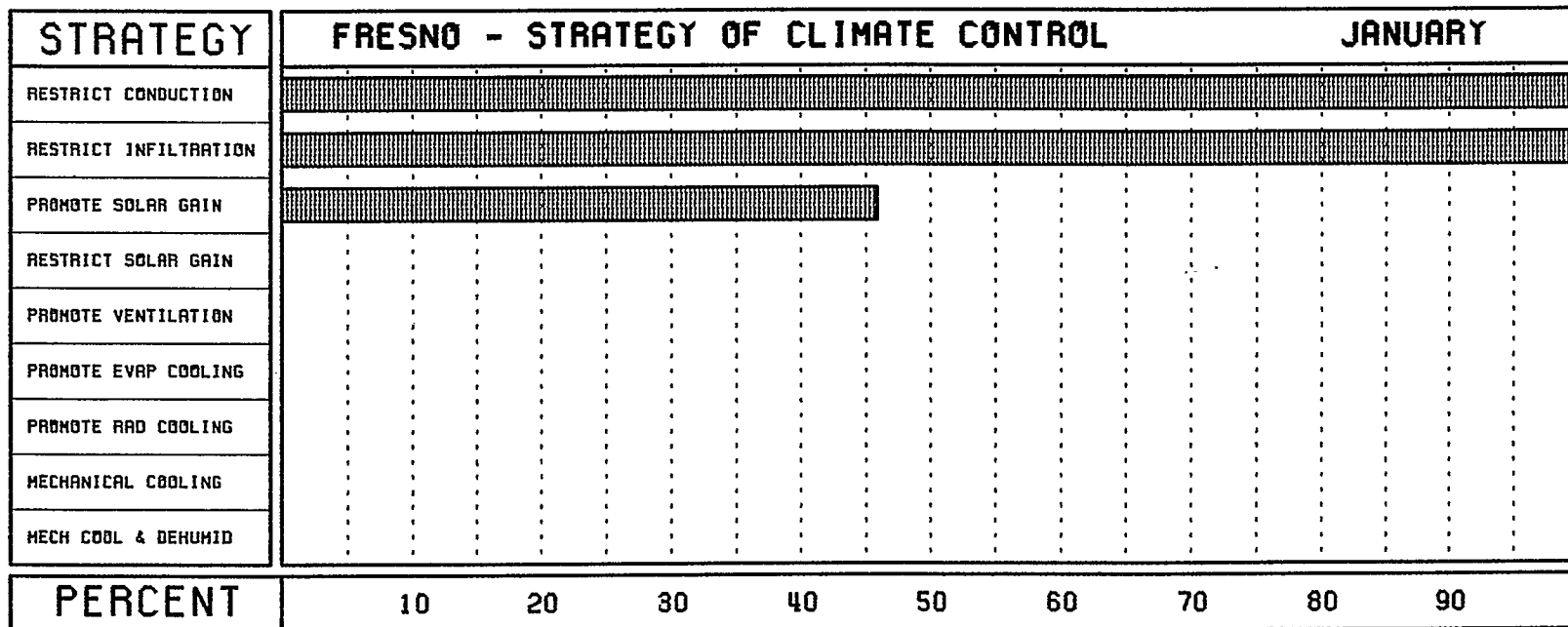
STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL SEPTEMBER																							
RESTRICT CONDUCTION																								
RESTRICT INFILTRATION																								
PROMOTE SOLAR GAIN																								
RESTRICT SOLAR GAIN																								
PROMOTE VENTILATION																								
PROMOTE EVAP COOLING																								
PROMOTE RAD COOLING																								
MECHANICAL COOLING																								
MECH COOL & DEHUMID																								
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

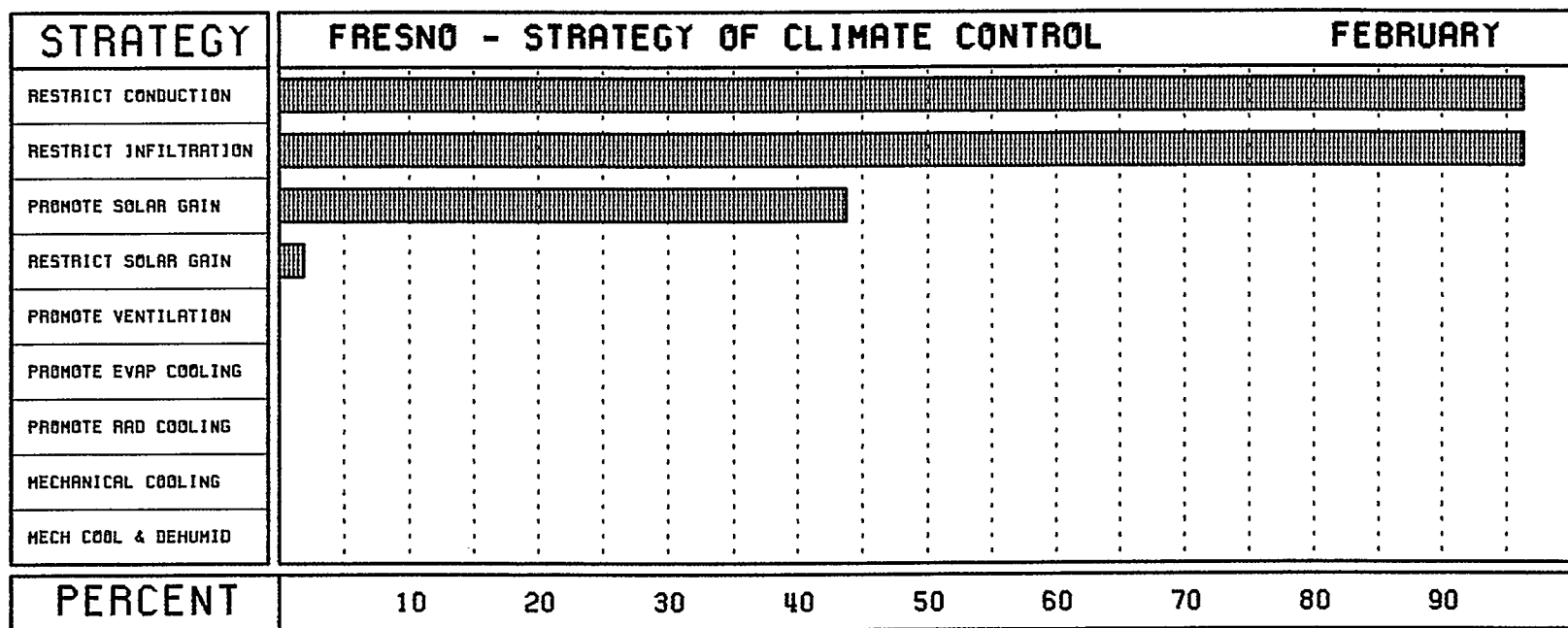
STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL																								OCTOBER
RESTRICT CONDUCTION																									
RESTRICT INFILTRATION																									
PROMOTE SOLAR GAIN																									
RESTRICT SOLAR GAIN																									
PROMOTE VENTILATION																									
PROMOTE EVAP COOLING																									
PROMOTE RAD COOLING																									
MECHANICAL COOLING																									
MECH COOL & DEHUMID																									
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

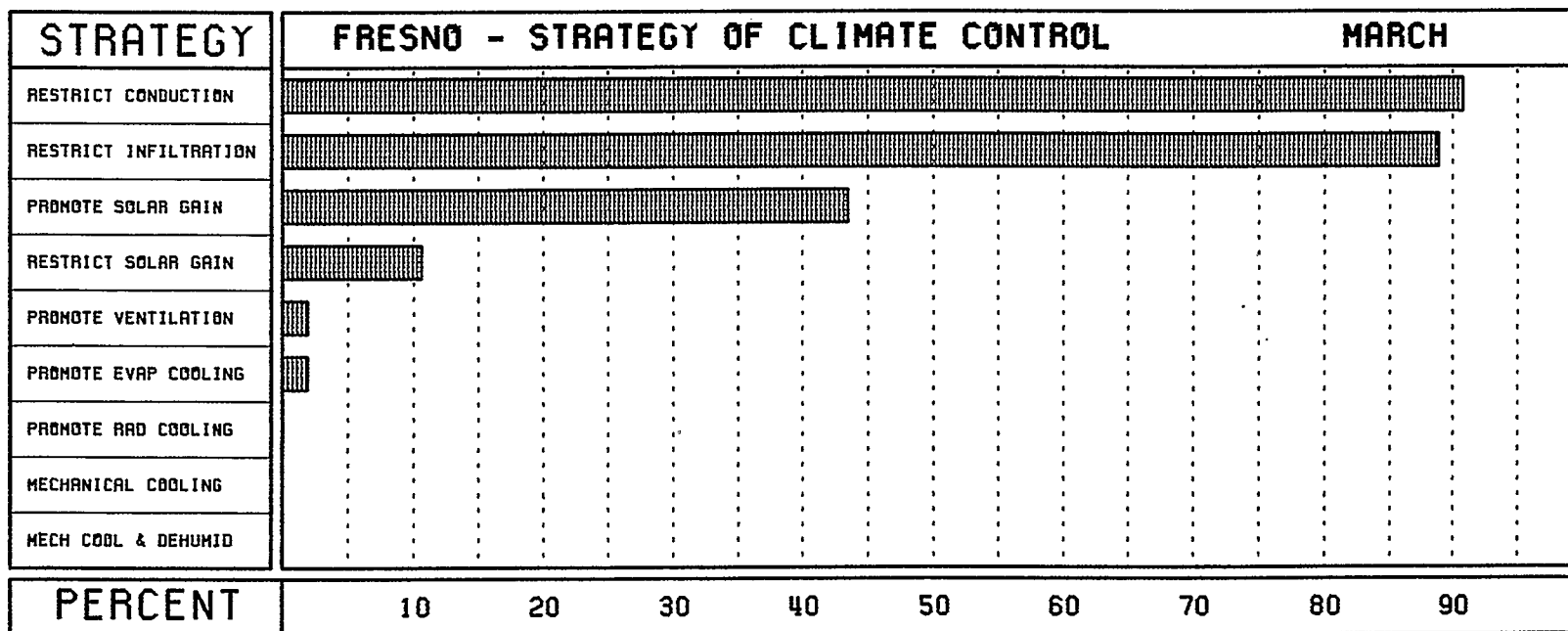
STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL																	NOVEMBER							
RESTRICT CONDUCTION																									
RESTRICT INFILTRATION																									
PROMOTE SOLAR GAIN																									
RESTRICT SOLAR GAIN																									
PROMOTE VENTILATION																									
PROMOTE EVAP COOLING																									
PROMOTE RAD COOLING																									
MECHANICAL COOLING																									
MECH COOL & DEHUMID																									
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

STRATEGY	FRESNO - STRATEGY OF CLIMATE CONTROL																DECEMBER								
RESTRICT CONDUCTION																									
RESTRICT INFILTRATION																									
PROMOTE SOLAR GAIN																									
RESTRICT SOLAR GAIN																									
PROMOTE VENTILATION																									
PROMOTE EVAP COOLING																									
PROMOTE RAD COOLING																									
MECHANICAL COOLING																									
MECH COOL & DEHUMID																									
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

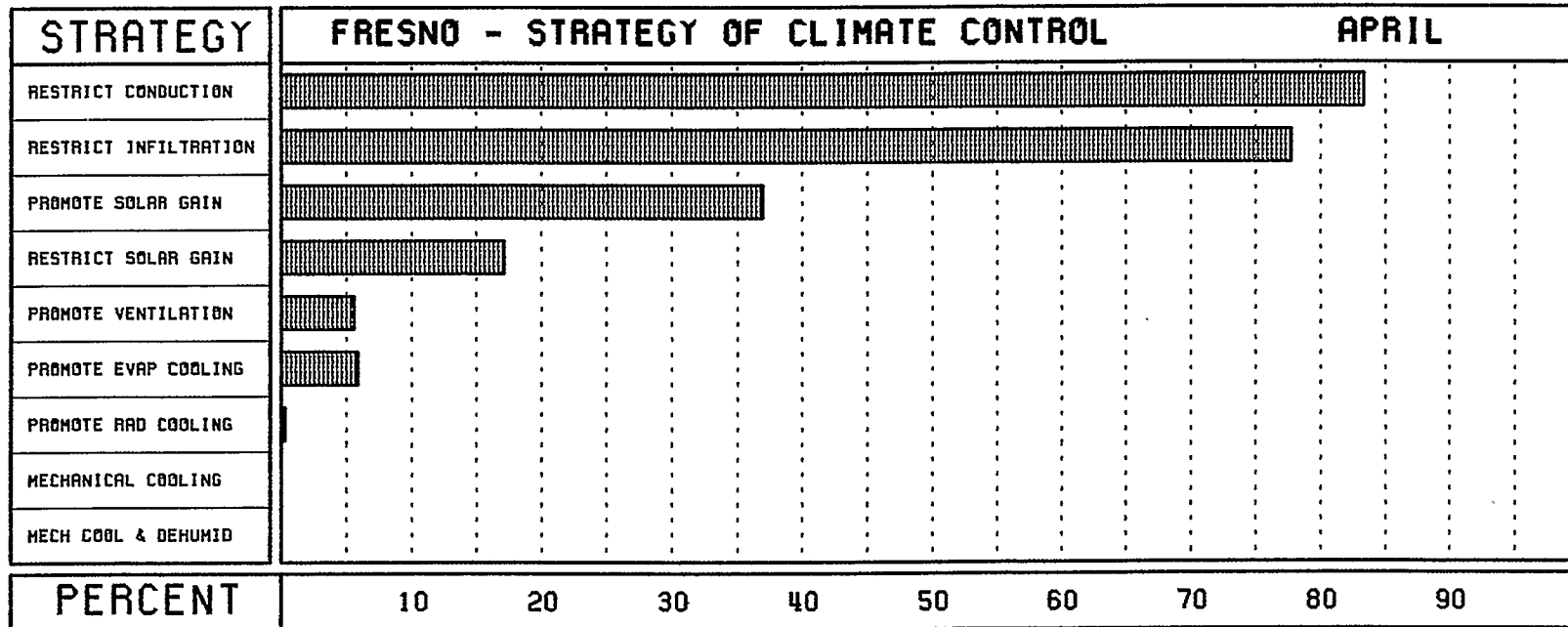
13. APPENDIX 4 - SCCBAR OUTPUT



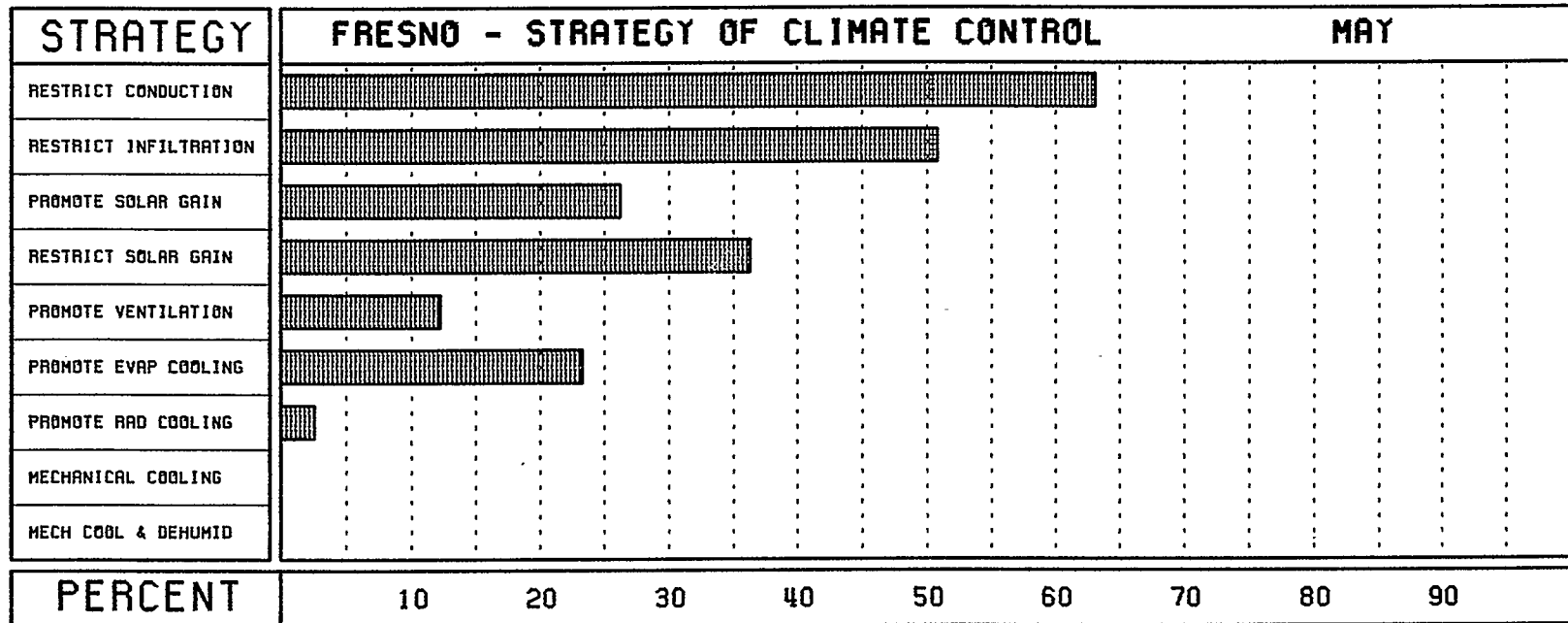


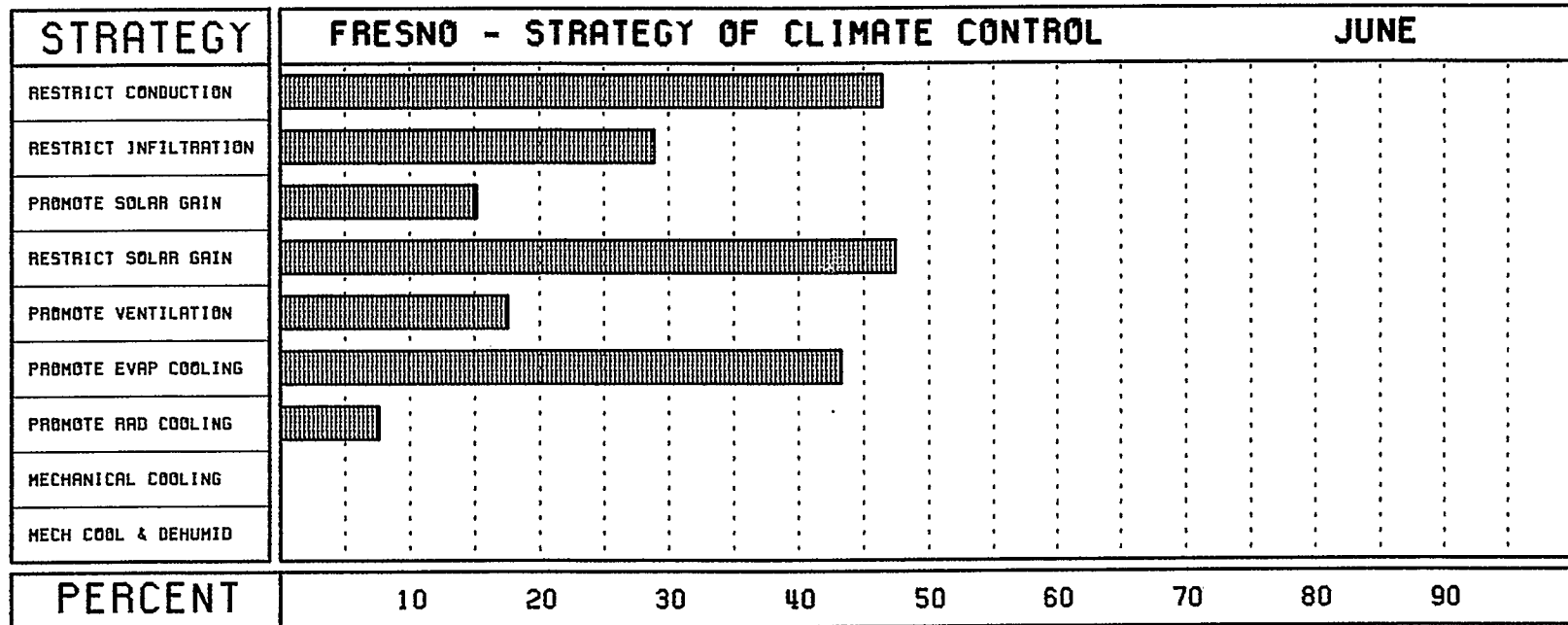


(V. ALLISON - 09/85)

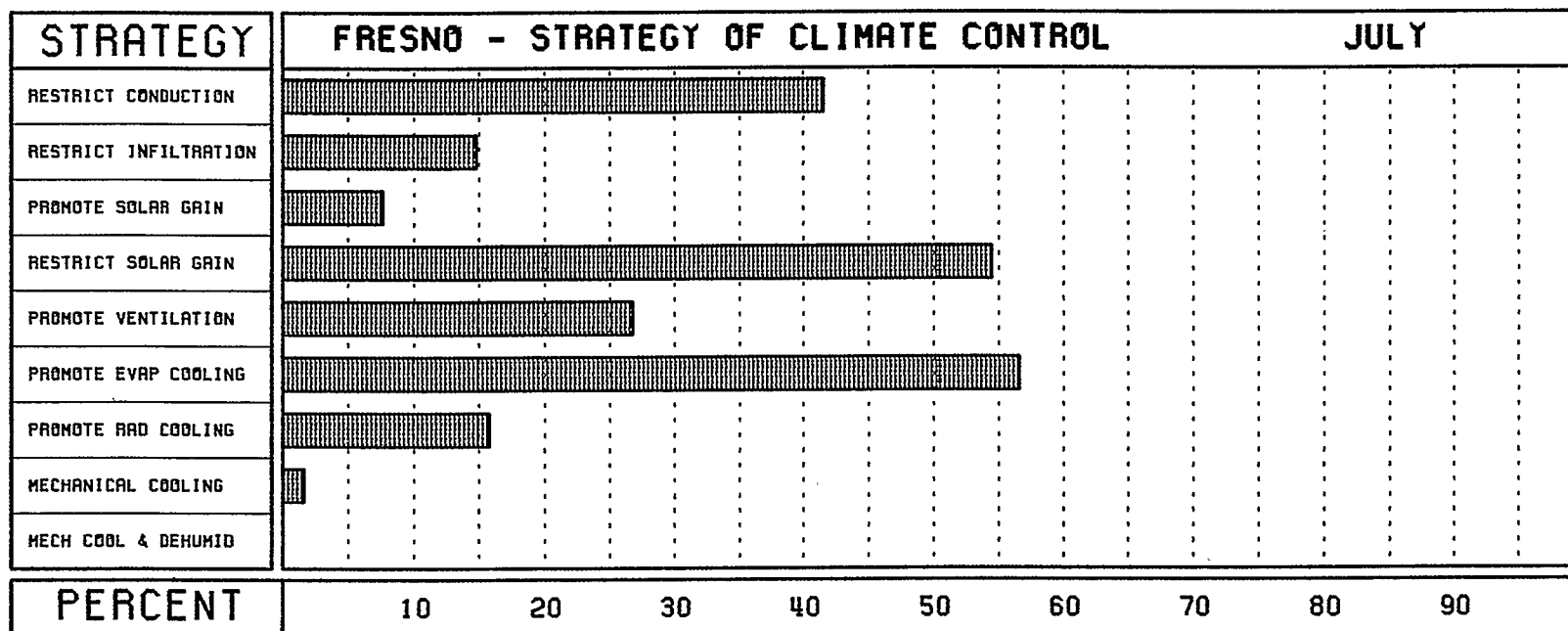


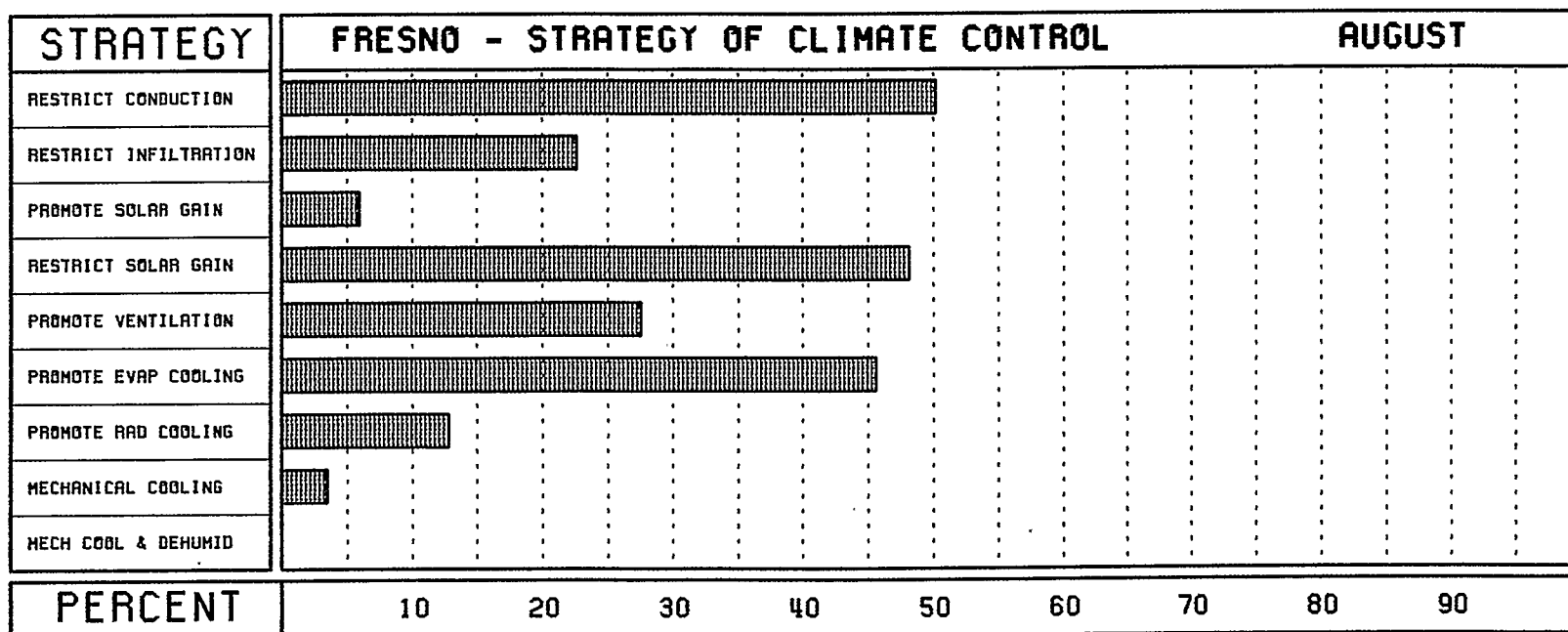
(V. ALLISON - 09/85)

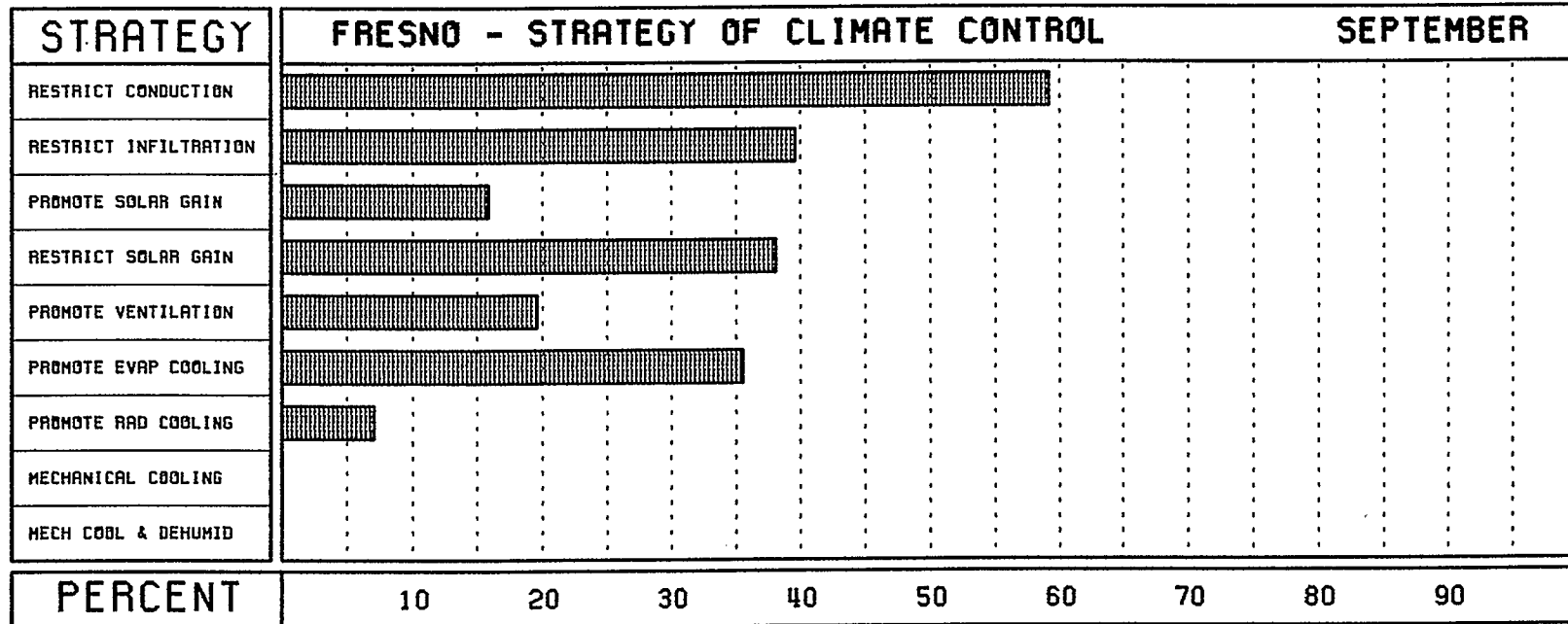




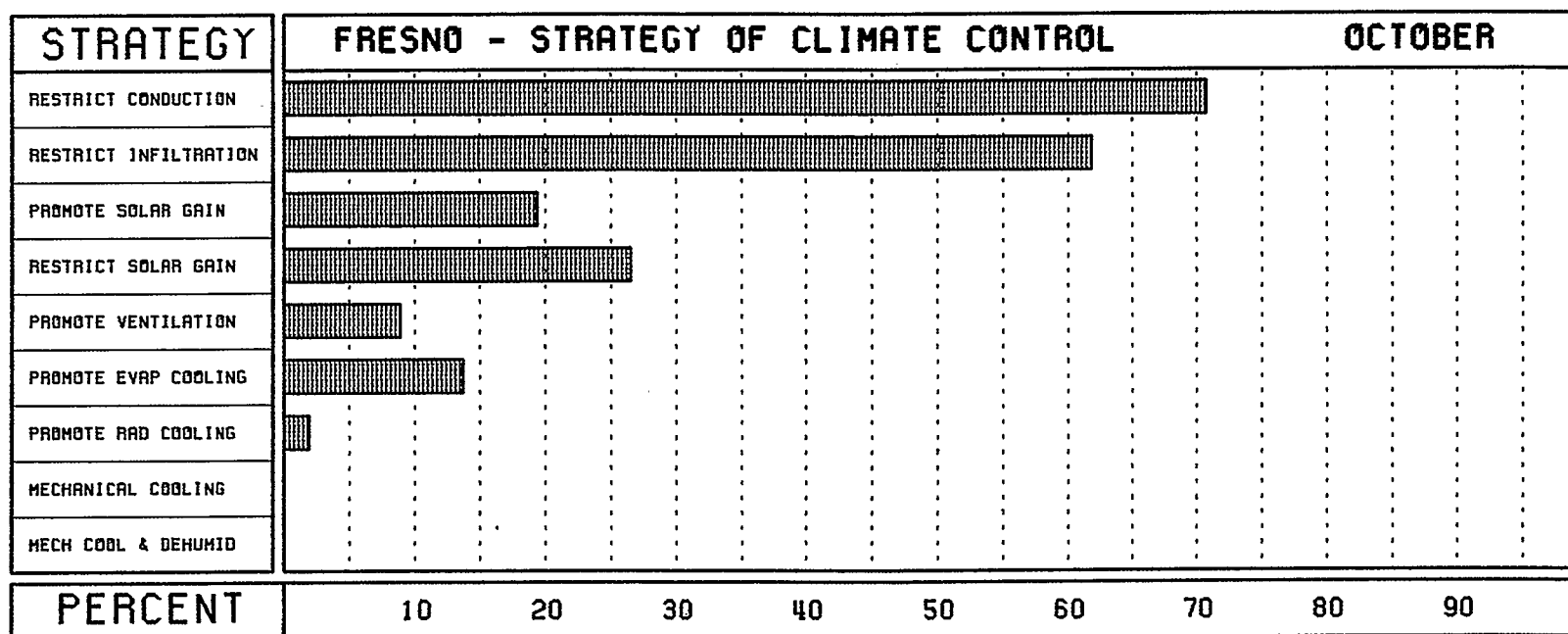
(V. ALLISON - 09/85)

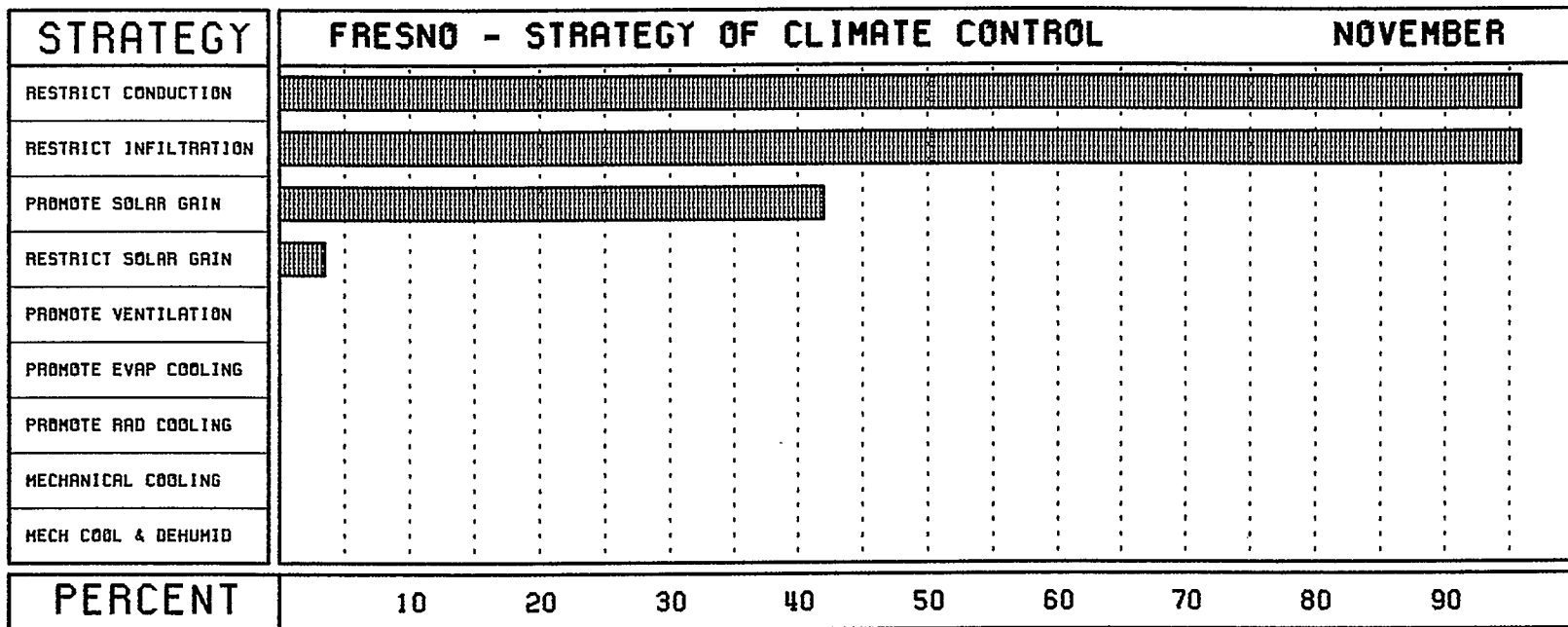


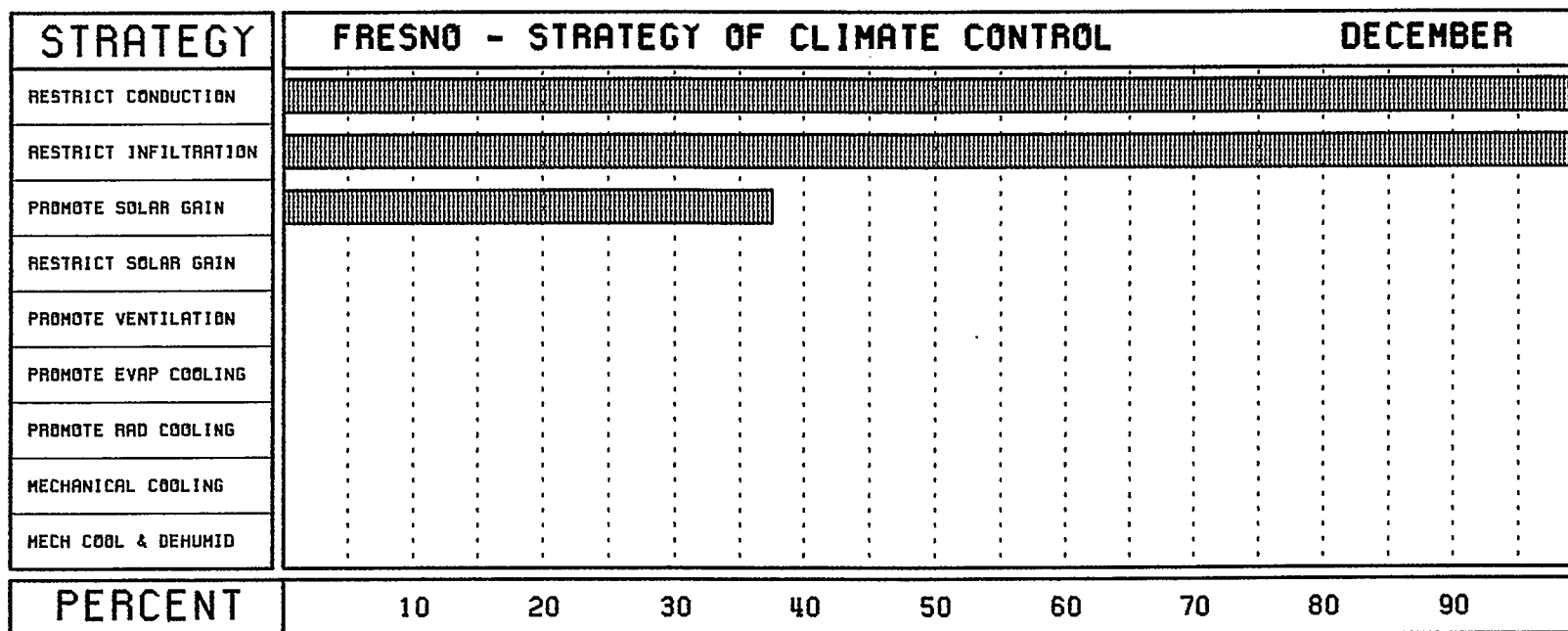


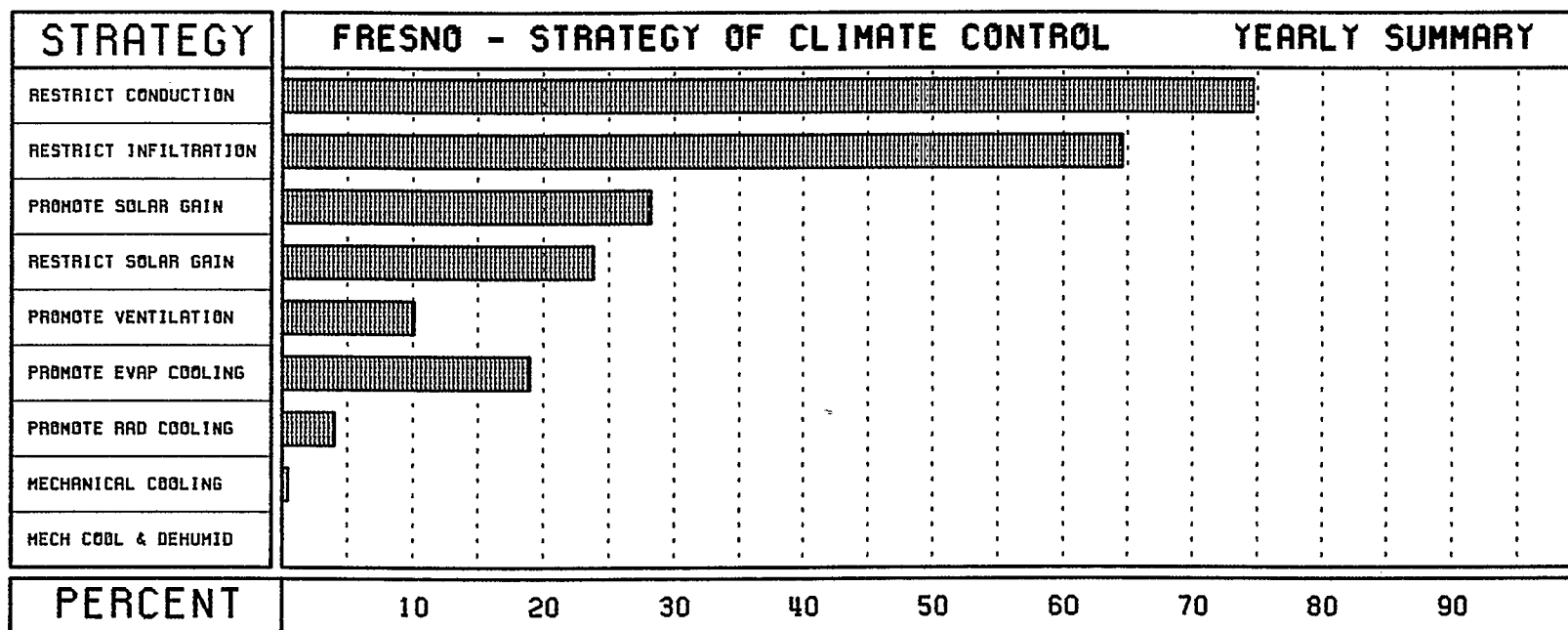


(V. ALLISON - 09/85)









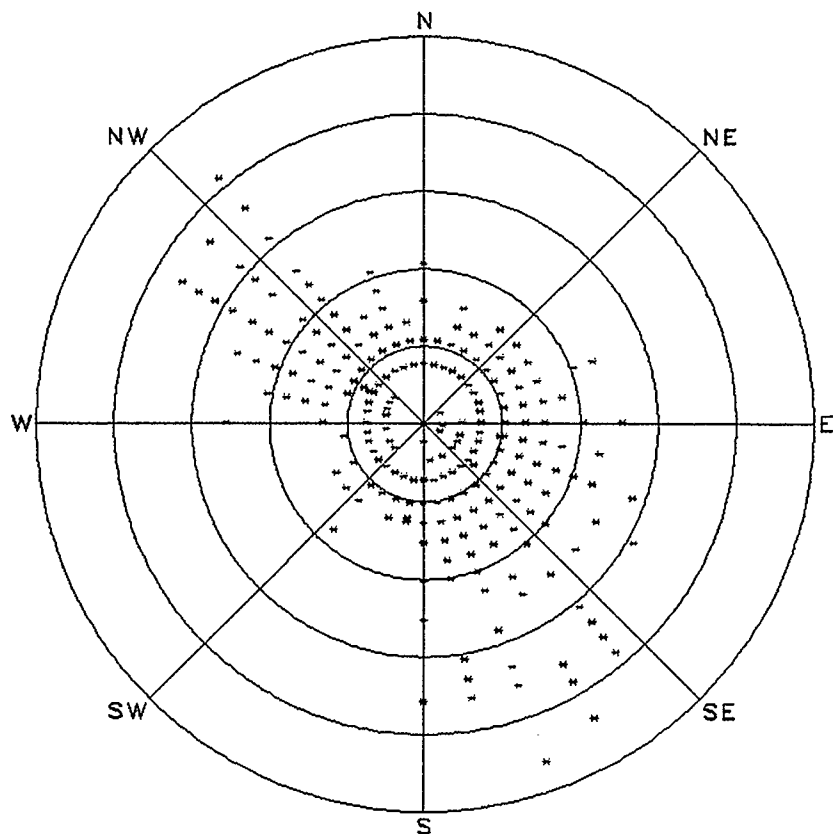
14. APPENDIX 5 - WINDROSE OUTPUT

FRESNO WINDROSE

HOUR KEY	
01 -	06
07 -	12
13 -	18
19 -	24

JANUARY

WINDSPEED INCREMENT = 2 M/S



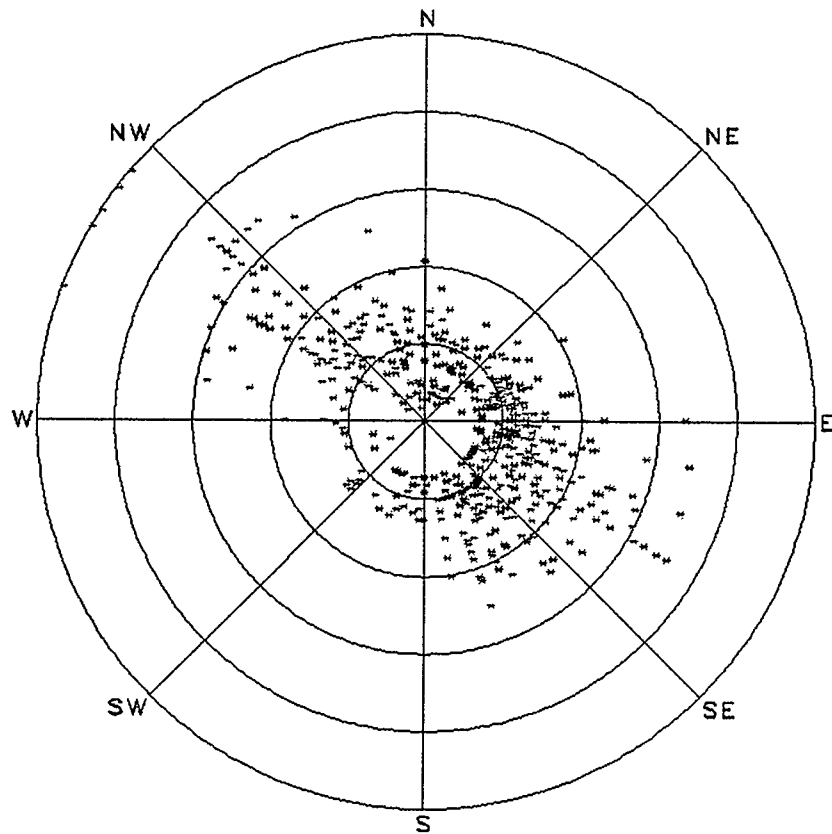
(V. ALLISON - 09/85)

FRESNO WINDROSE

HOUR KEY	
01	- 06
07	- 12
13	- 18
19	- 24

FEBRUARY

WINDSPEED INCREMENT = 2 M/S



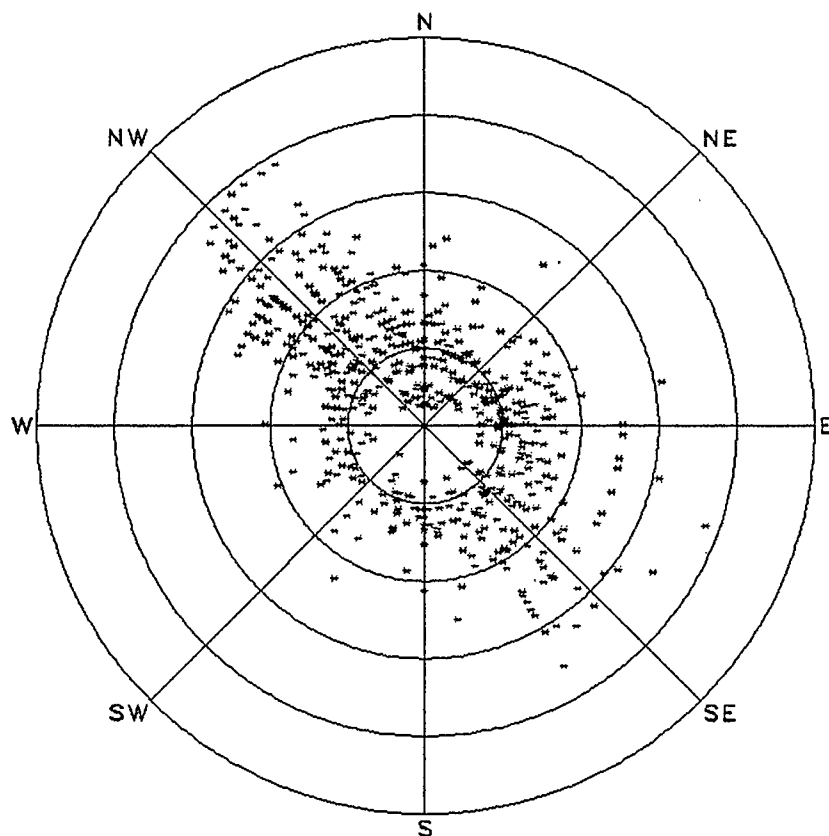
(V. ALLISON - 08/85)

FRESNO WINDROSE

HOUR KEY	
01	- 06
07	- 12
13	- 18
19	- 24

MARCH

WINDSPEED INCREMENT = 2 M/S



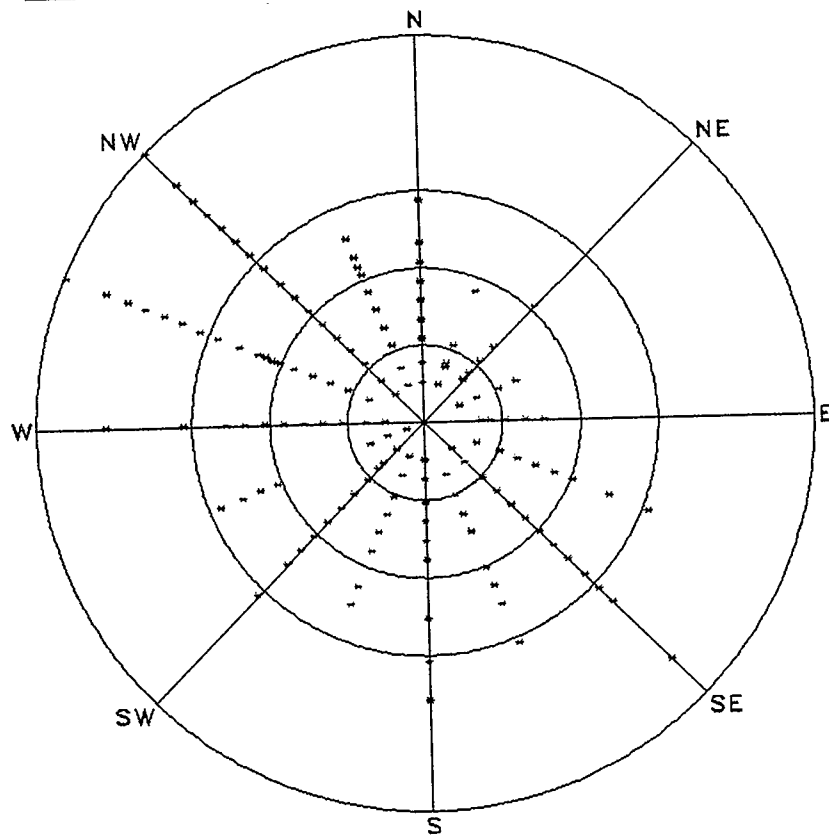
(V. ALLISON - 09/85)

FRESNO WINDROSE

APRIL

HOUR KEY	
01 -	06
07 -	12
13 -	18
19 -	24

WINDSPEED INCREMENT = 2 M/S



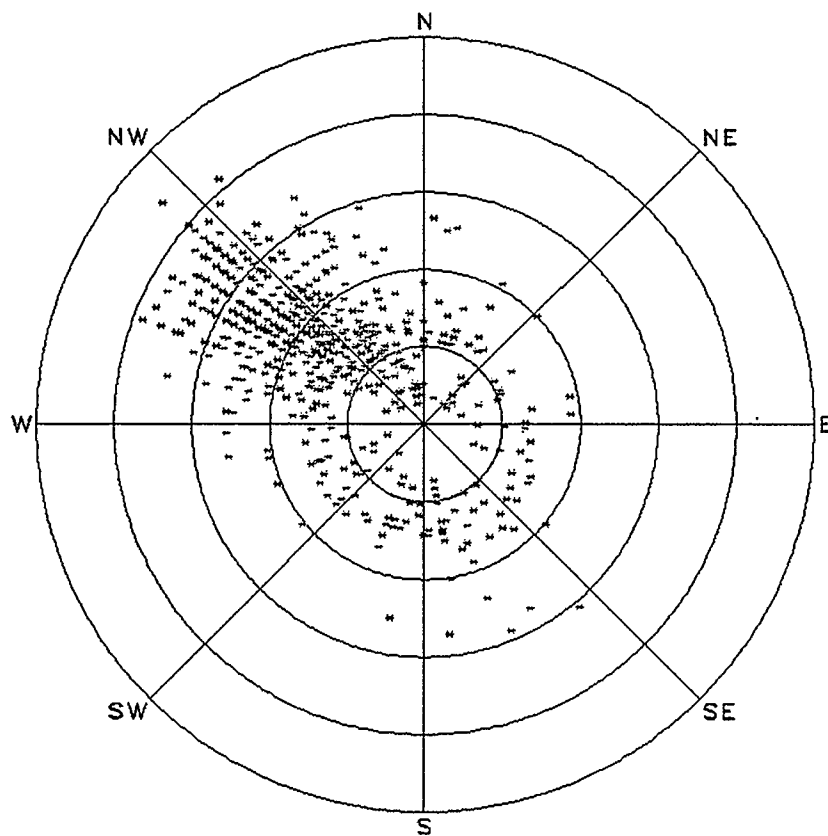
(V. ALLISON - 09/85)

FRESNO WINDROSE

HOUR KEY	
01	- 06
07	- 12
13	- 18
19	- 24

MAY

WINDSPEED INCREMENT = 2 M/S



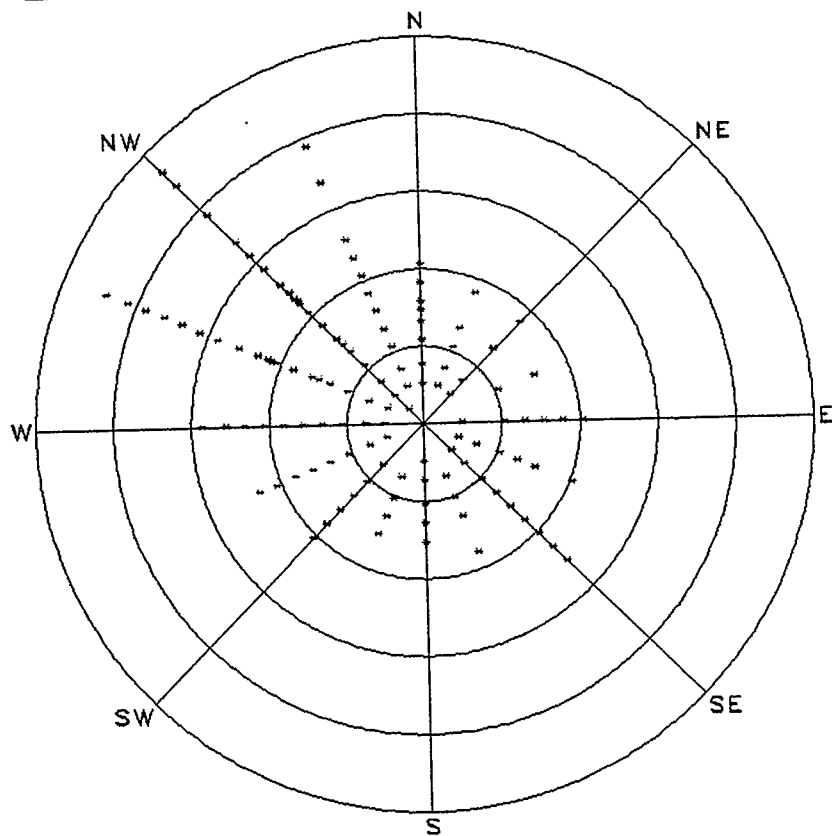
(V. ALLISON - 00/BB)

FRESNO WINDROSE

JUNE

HOUR KEY	
01	- 06
07	- 12
13	- 18
19	- 24

WINDSPEED INCREMENT = 2 M/S



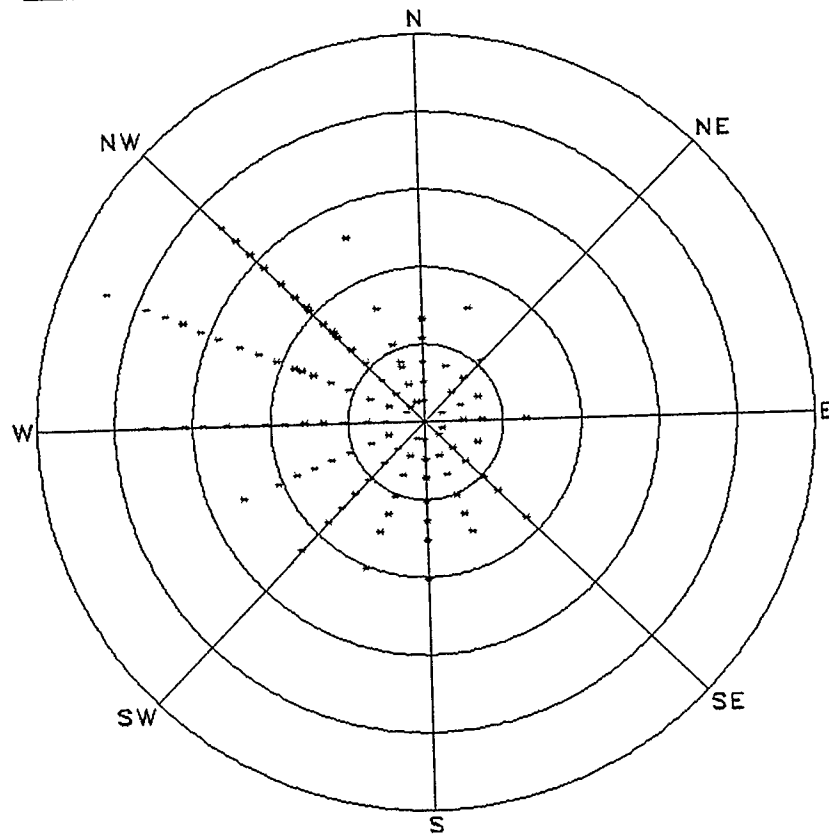
(V. ALLISON - 06/85)

FRESNO WINDROSE

JULY

HOUR KEY	
01 -	06
07 -	12
13 -	18
19 -	24

WINDSPEED INCREMENT = 2 M/S



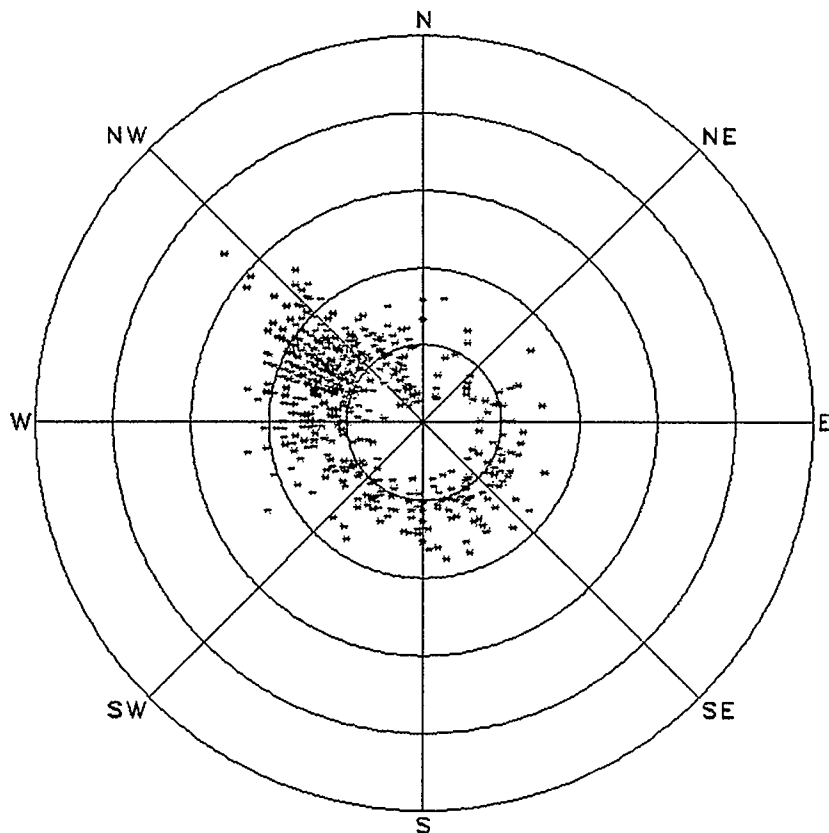
(V. ALLISON - 09/85)

FRESNO WINDROSE

HOUR KEY	
01	- 06
07	- 12
13	- 18
19	- 24

AUGUST

WINDSPEED INCREMENT = 2 M/S



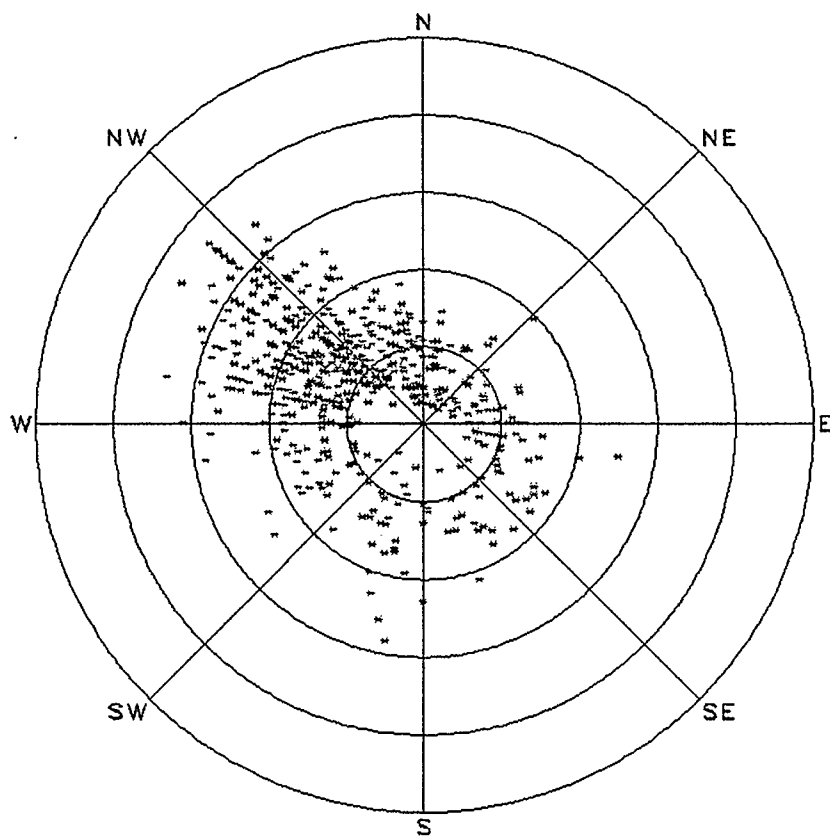
(V. ALLISON - 00/85)

FRESNO WINDROSE

HOUR KEY	
01	- 06
07	- 12
13	- 18
19	- 24

SEPTEMBER

WINDSPEED INCREMENT = 2 M/S



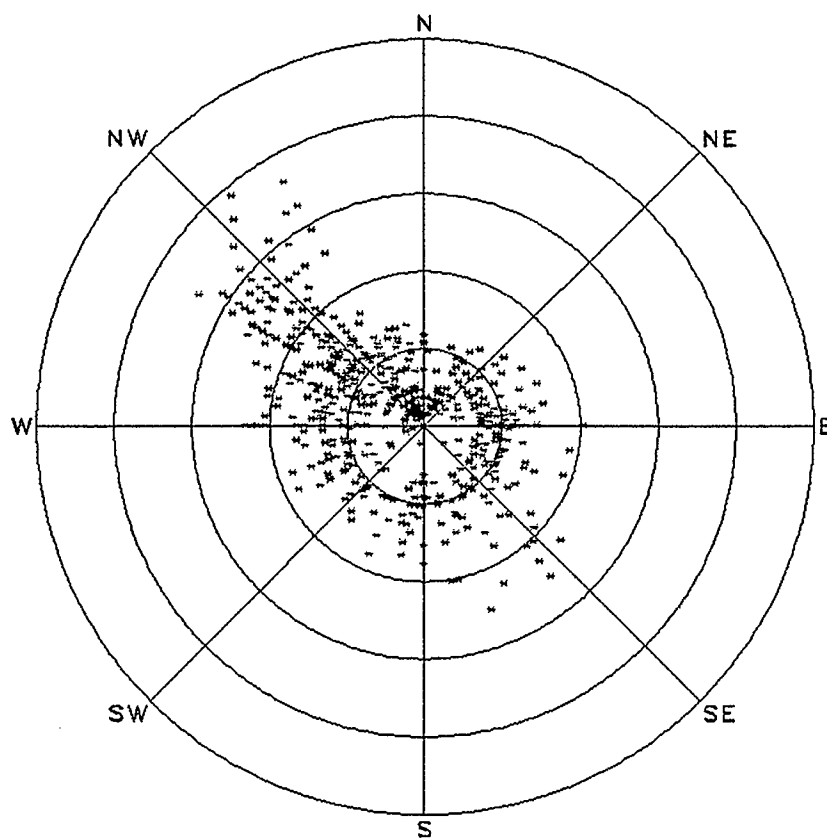
(V. ALLISON - 00/85)

FRESNO WINDROSE

HOUR KEY	
01	— 06
07	— 12
13	— 18
19	— 24

OCTOBER

WINDSPEED INCREMENT = 2 M/S



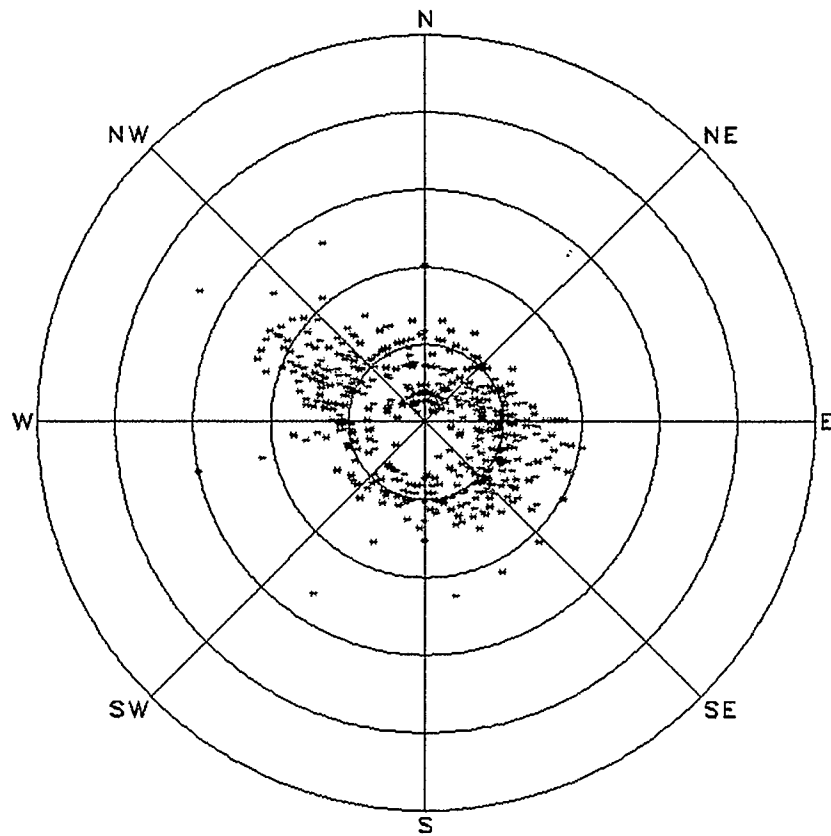
(V. ALLISON - 06/85)

FRESNO WINDROSE

HOUR KEY	
01	- 06
07	- 12
13	- 18
19	- 24

NOVEMBER

WINDSPEED INCREMENT = 2 M/S



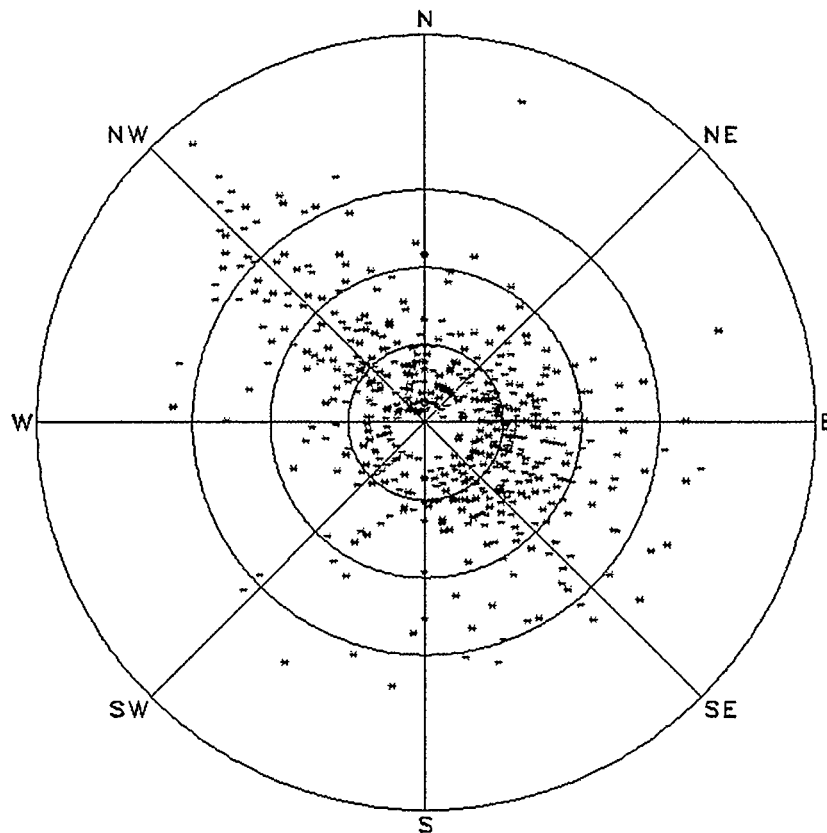
(V. ALLISON - 09/85)

FRESNO WINDROSE

HOUR KEY	
01 -	06
07 -	12
13 -	18
19 -	24

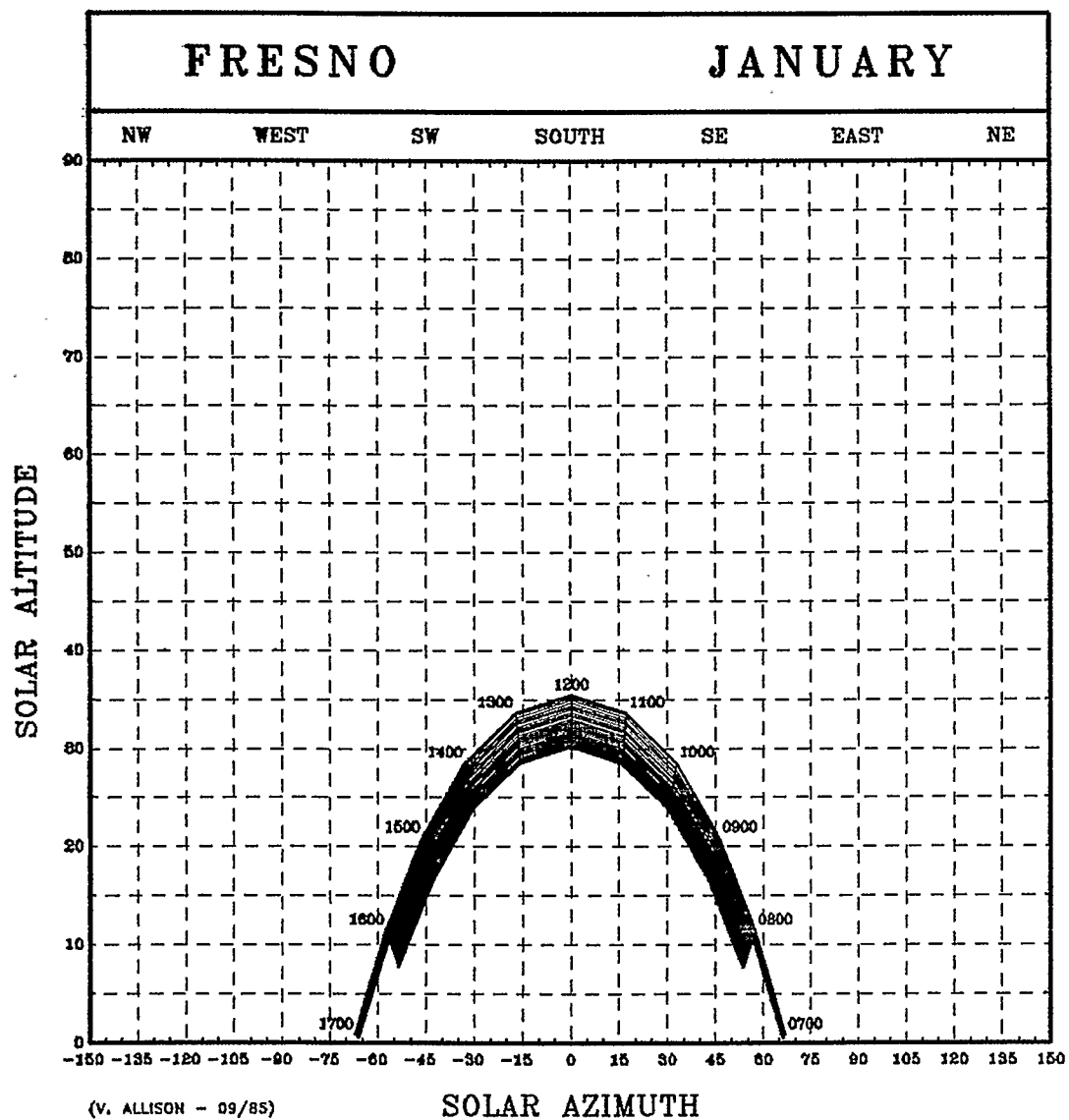
DECEMBER

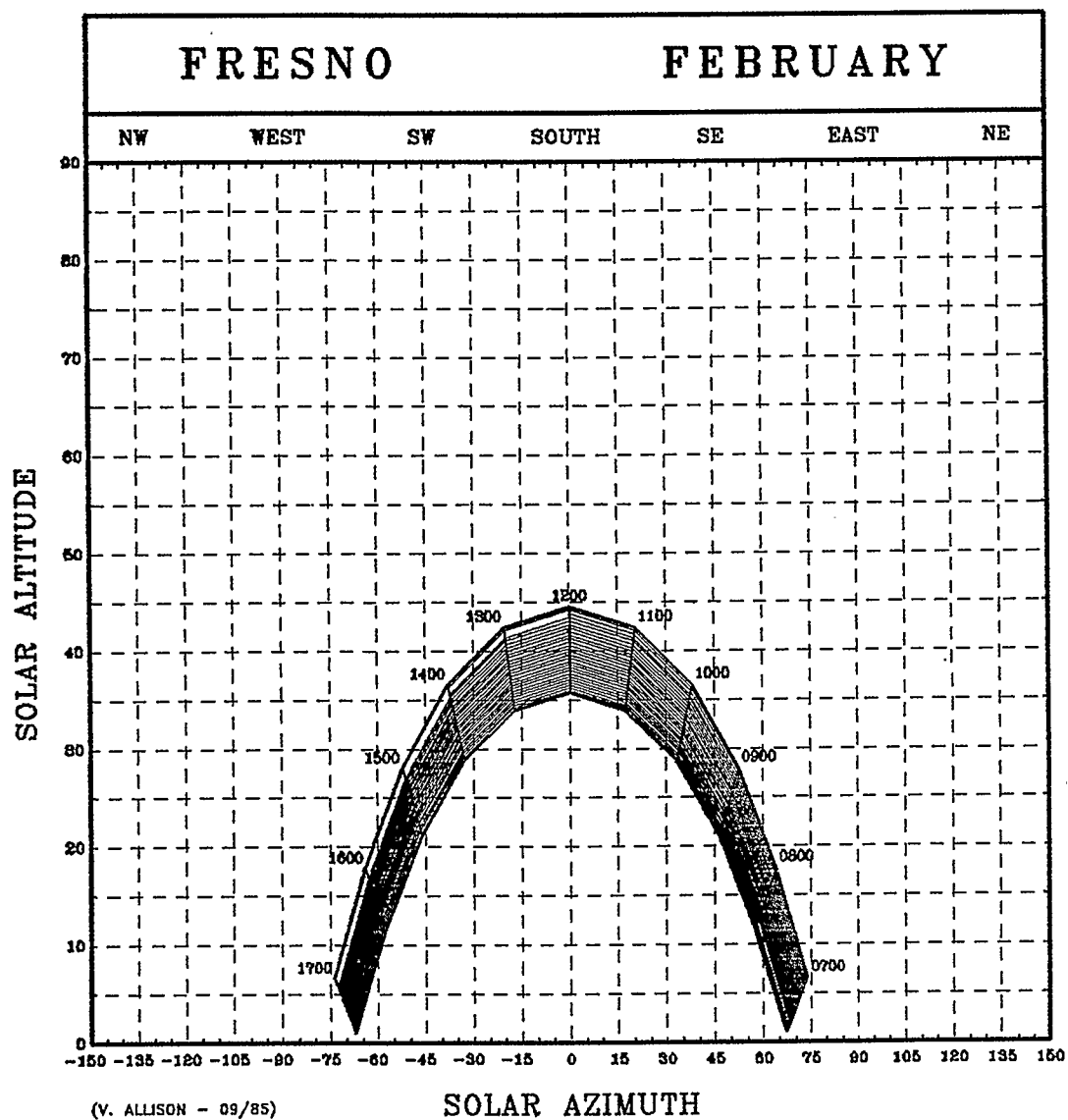
WINDSPEED INCREMENT = 2 M/S

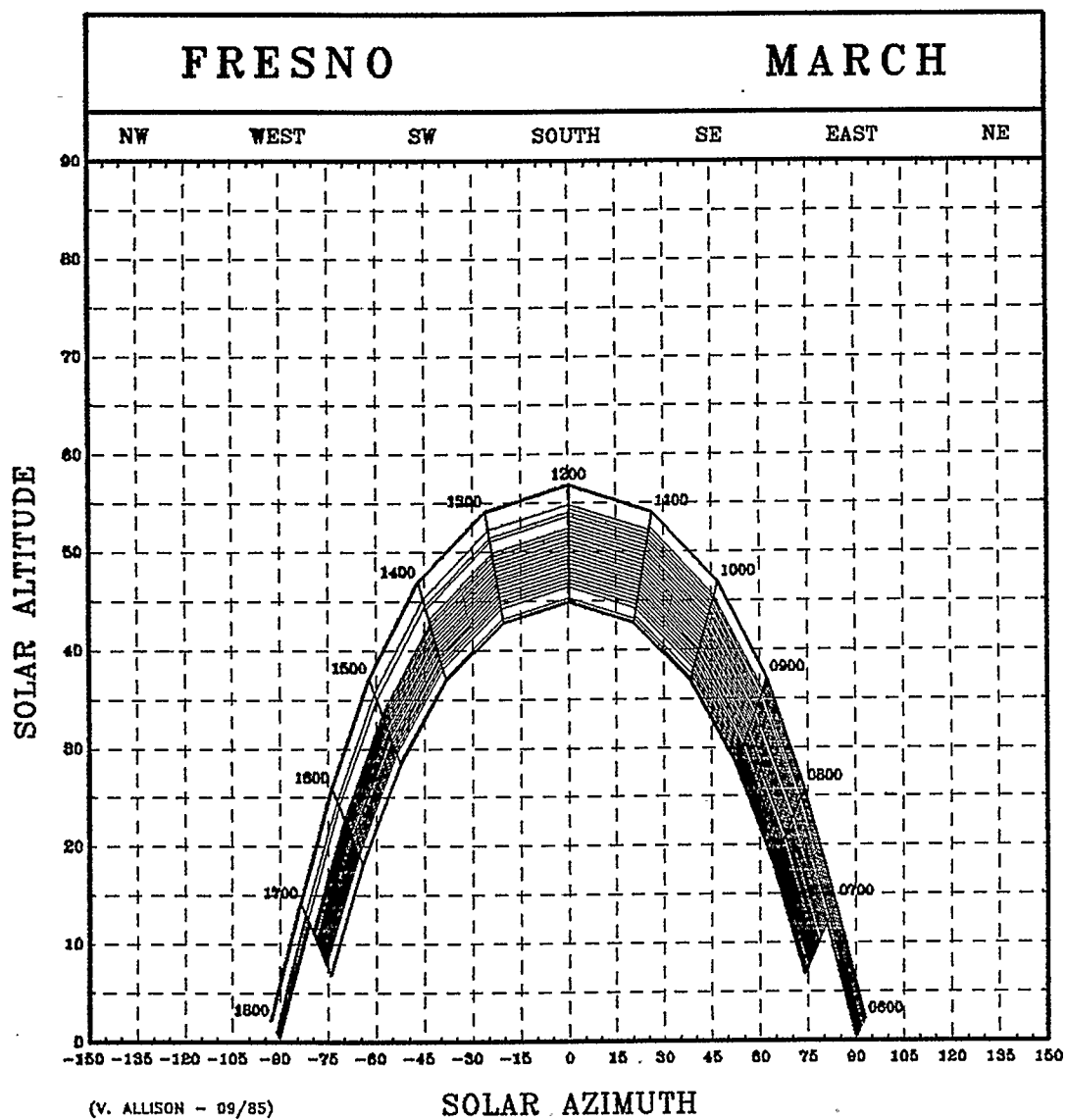


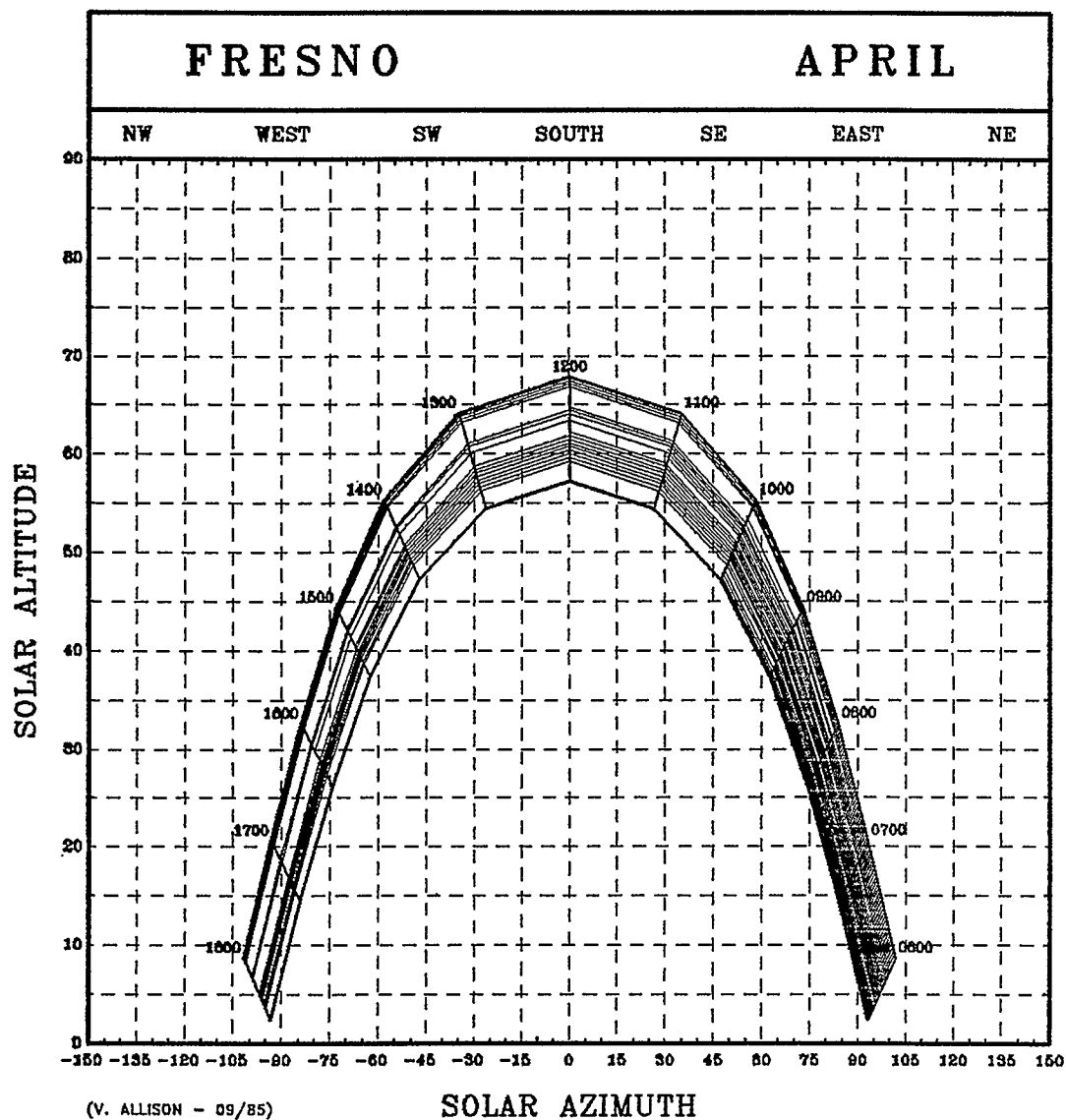
(V. ALLISON - 09/85)

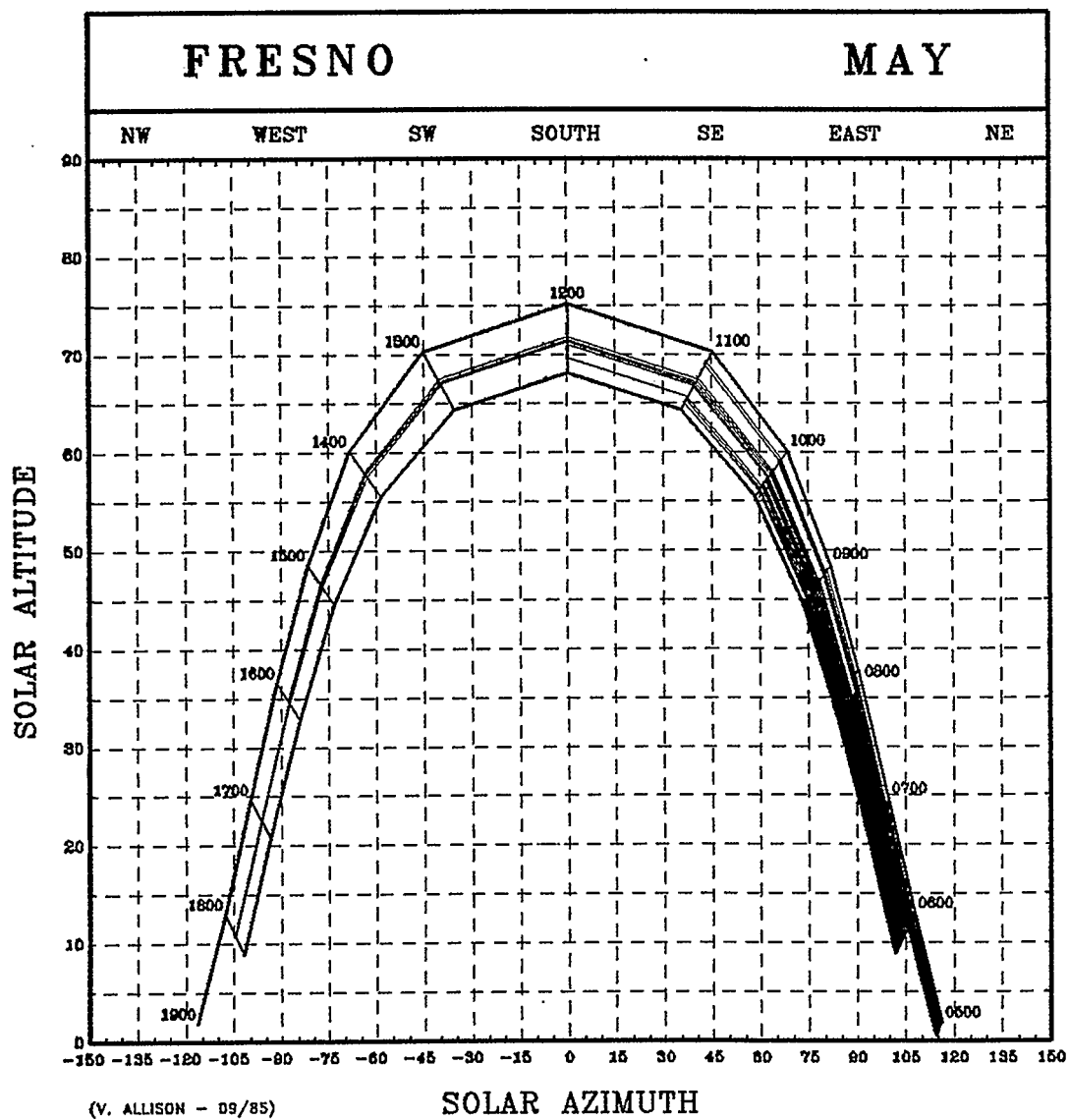
15. APPENDIX 6 - SOLPATH OUTPUT

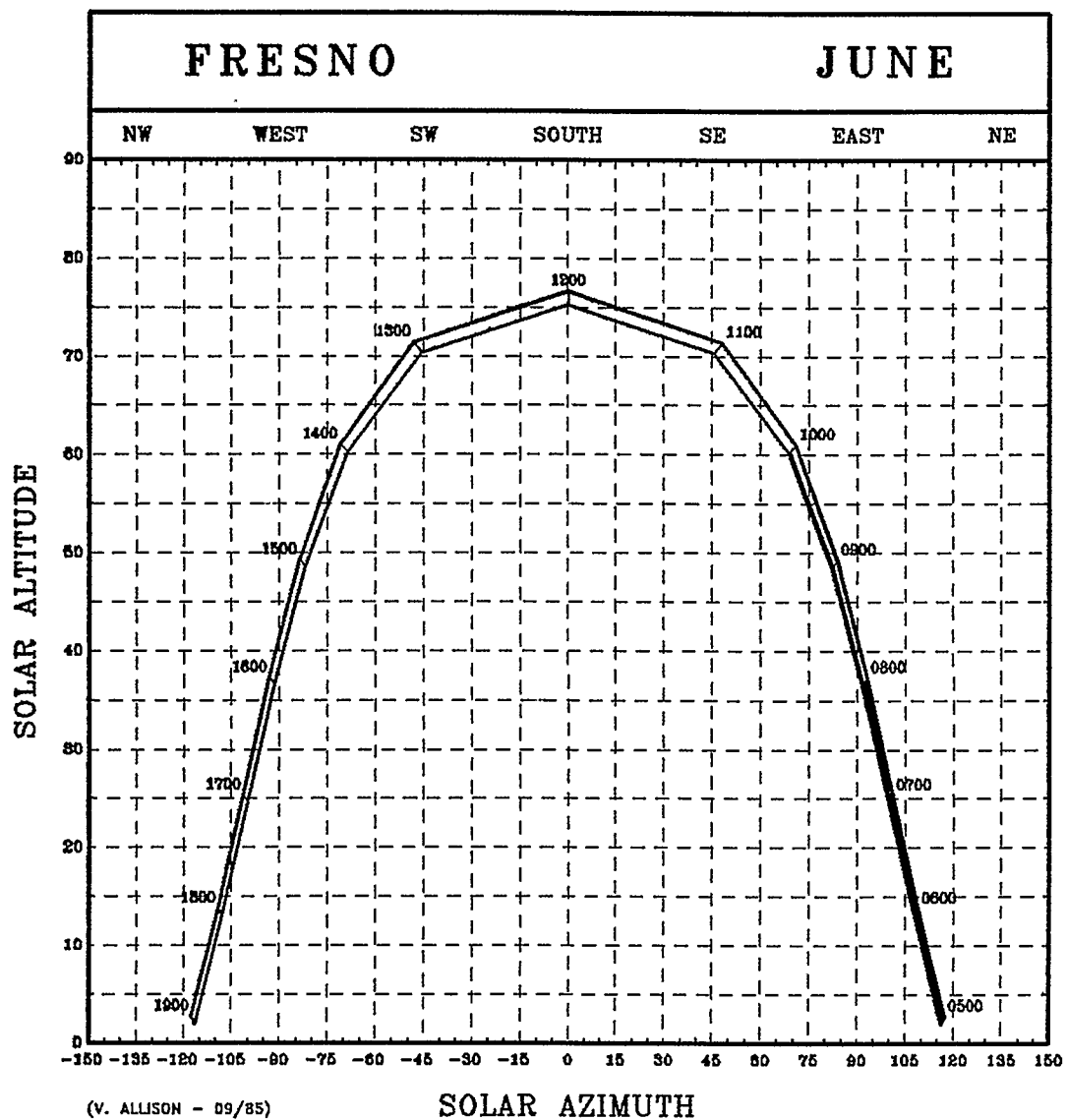


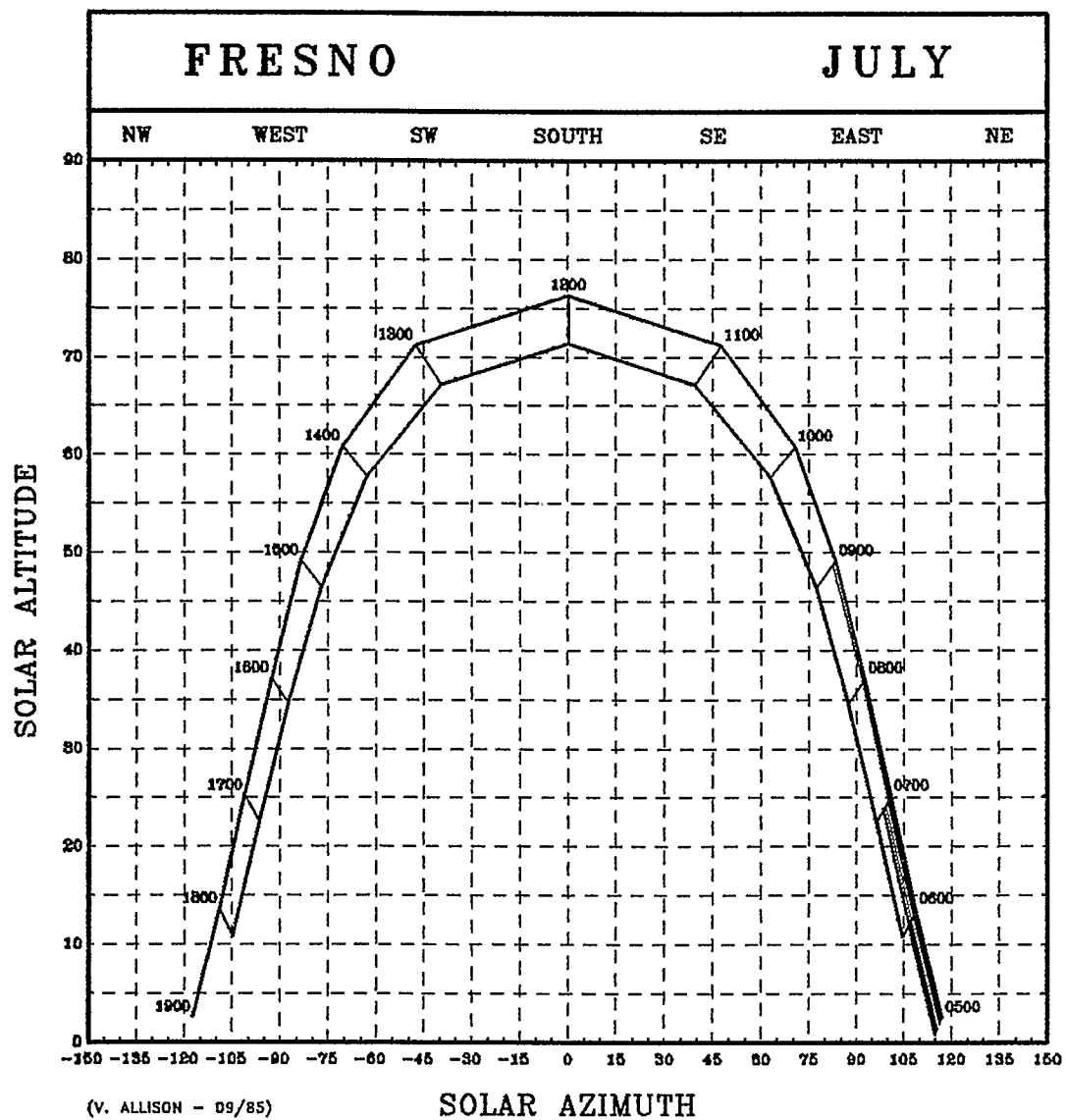


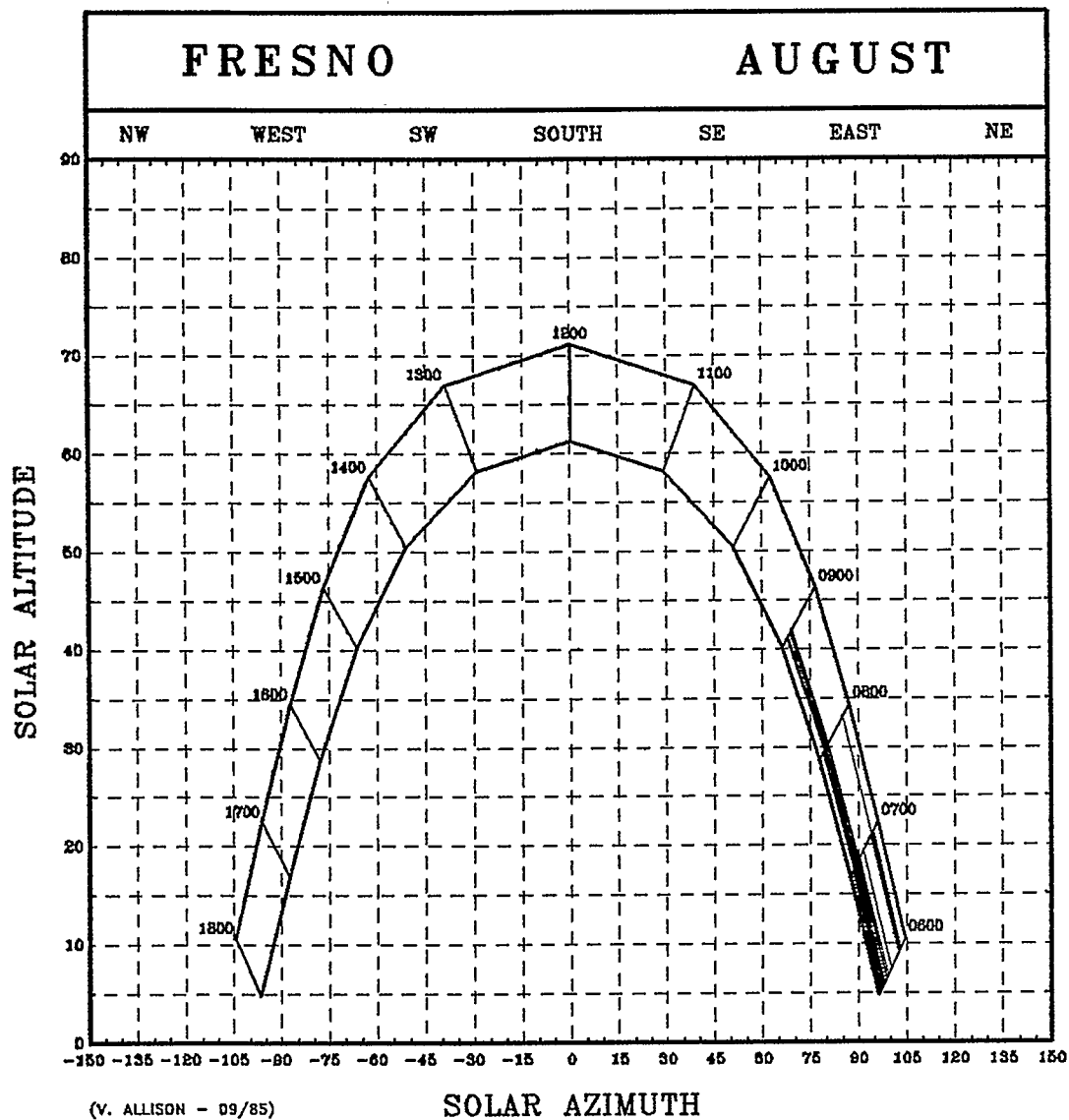


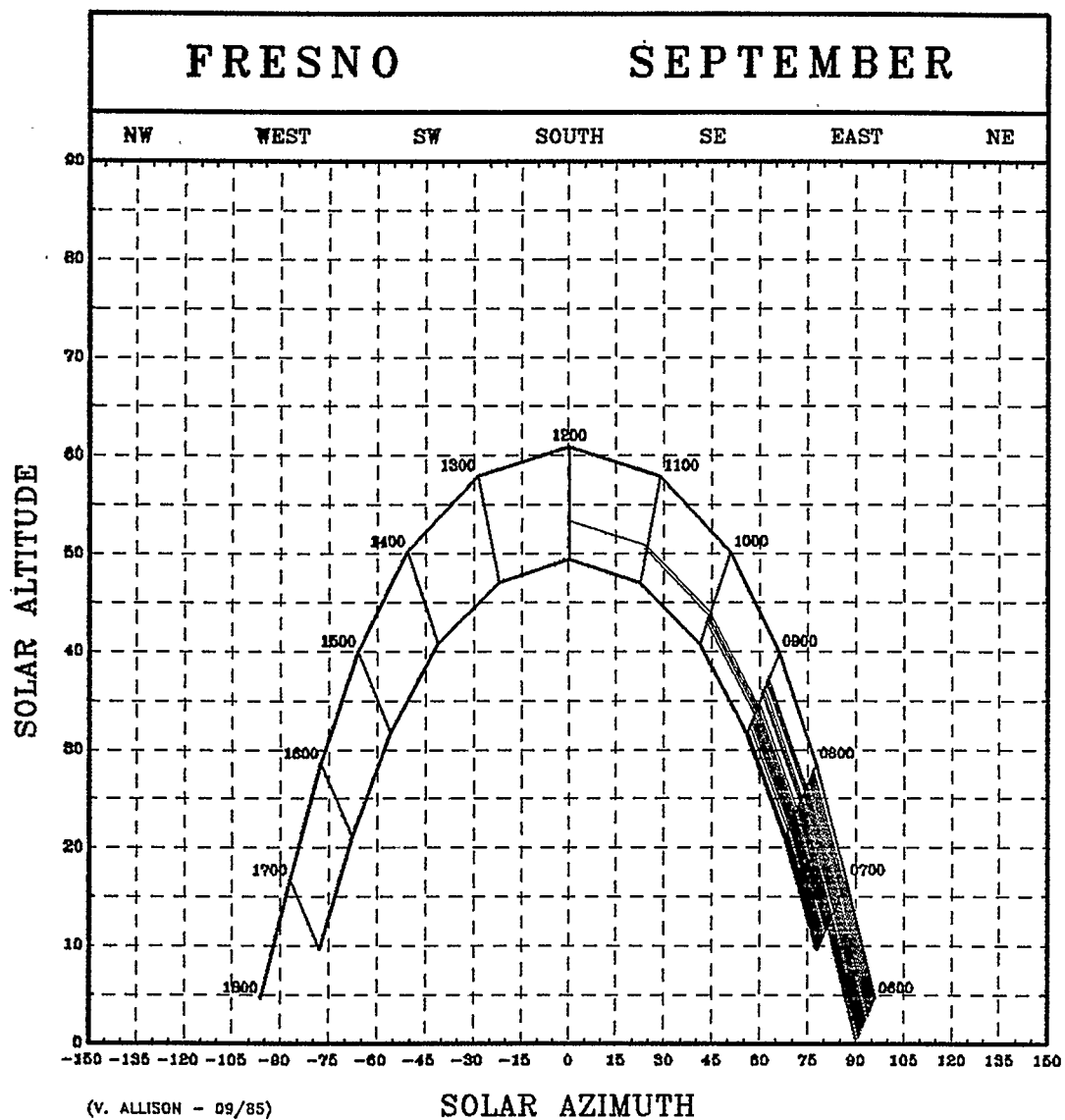


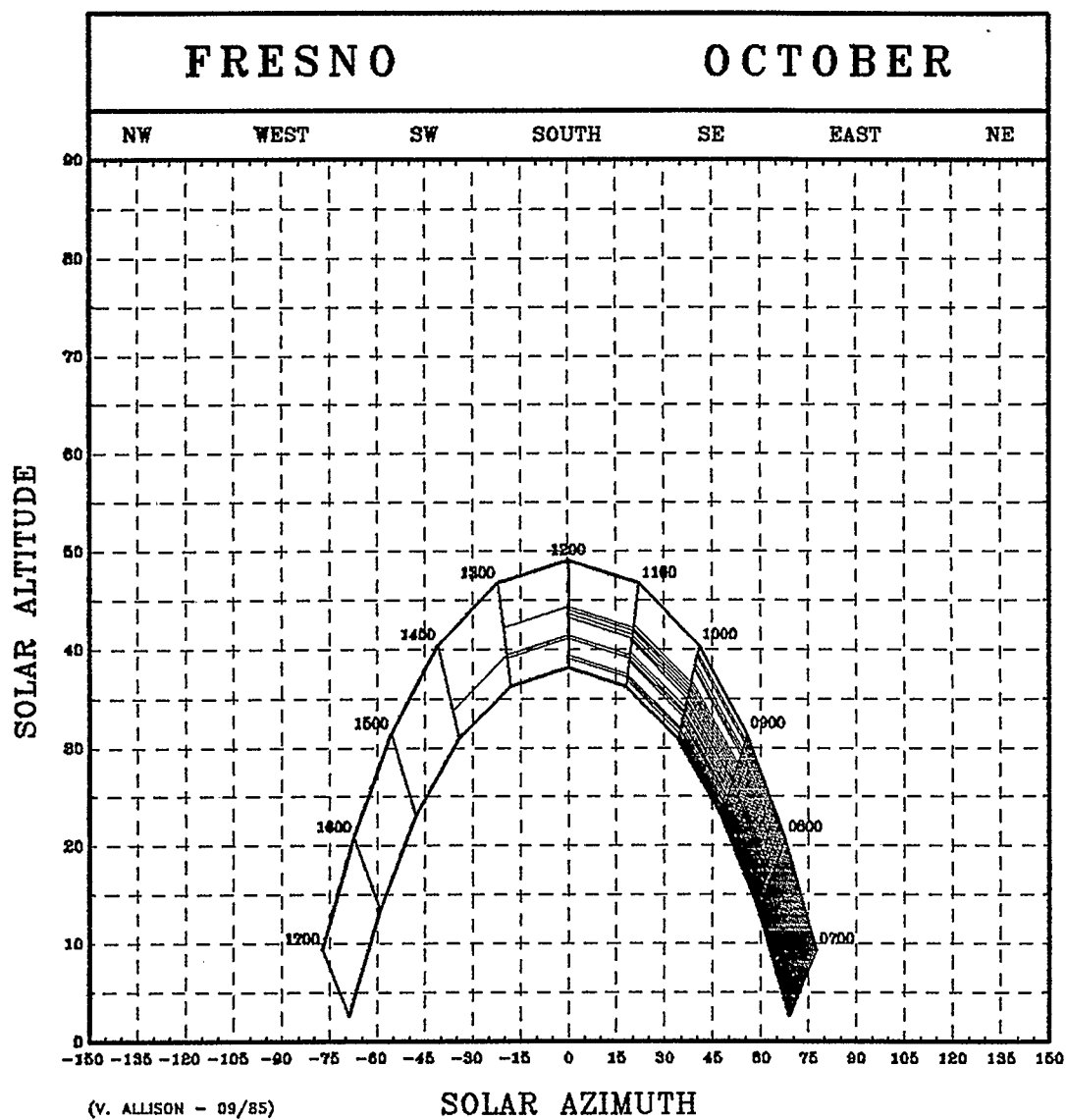


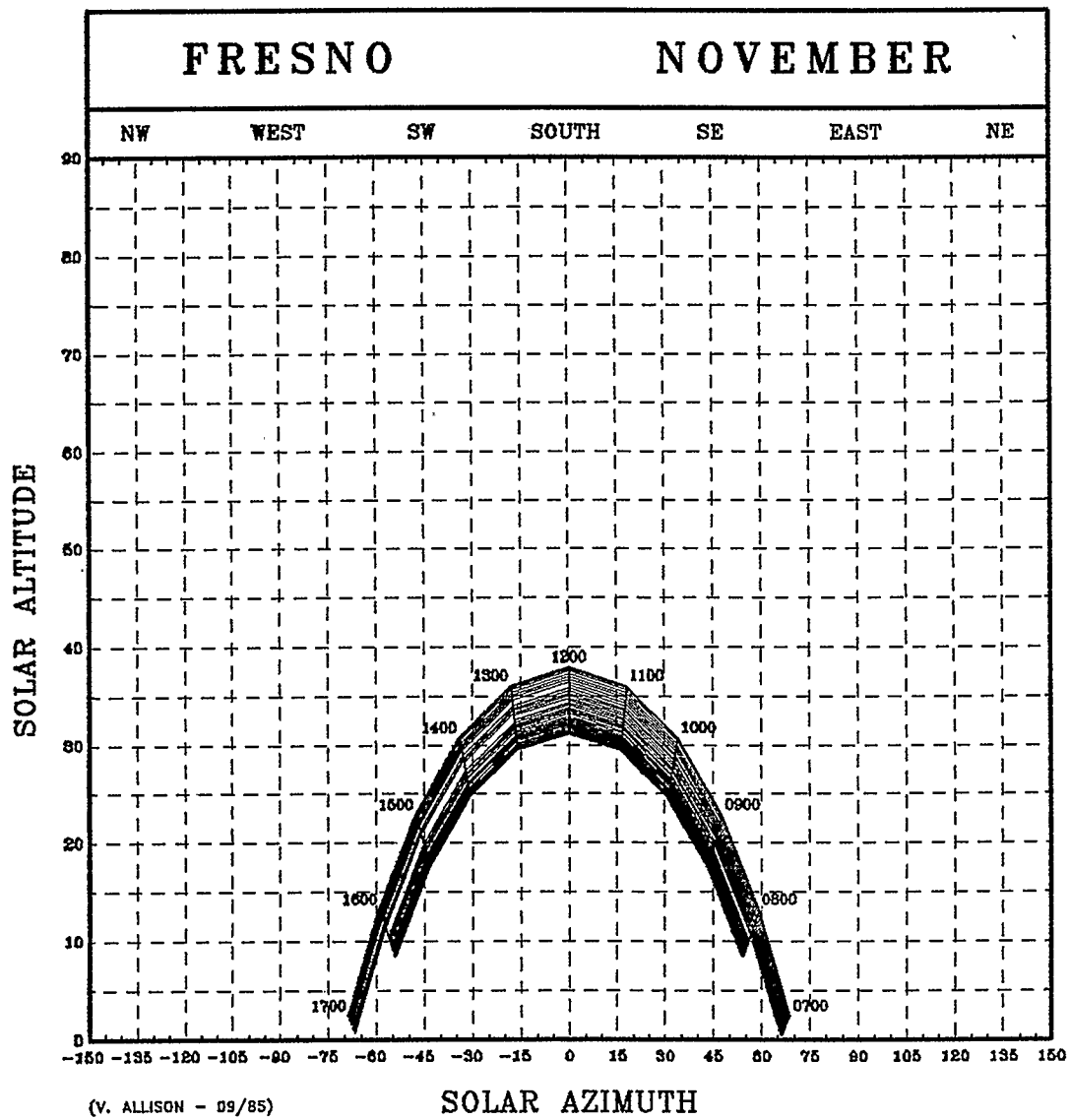


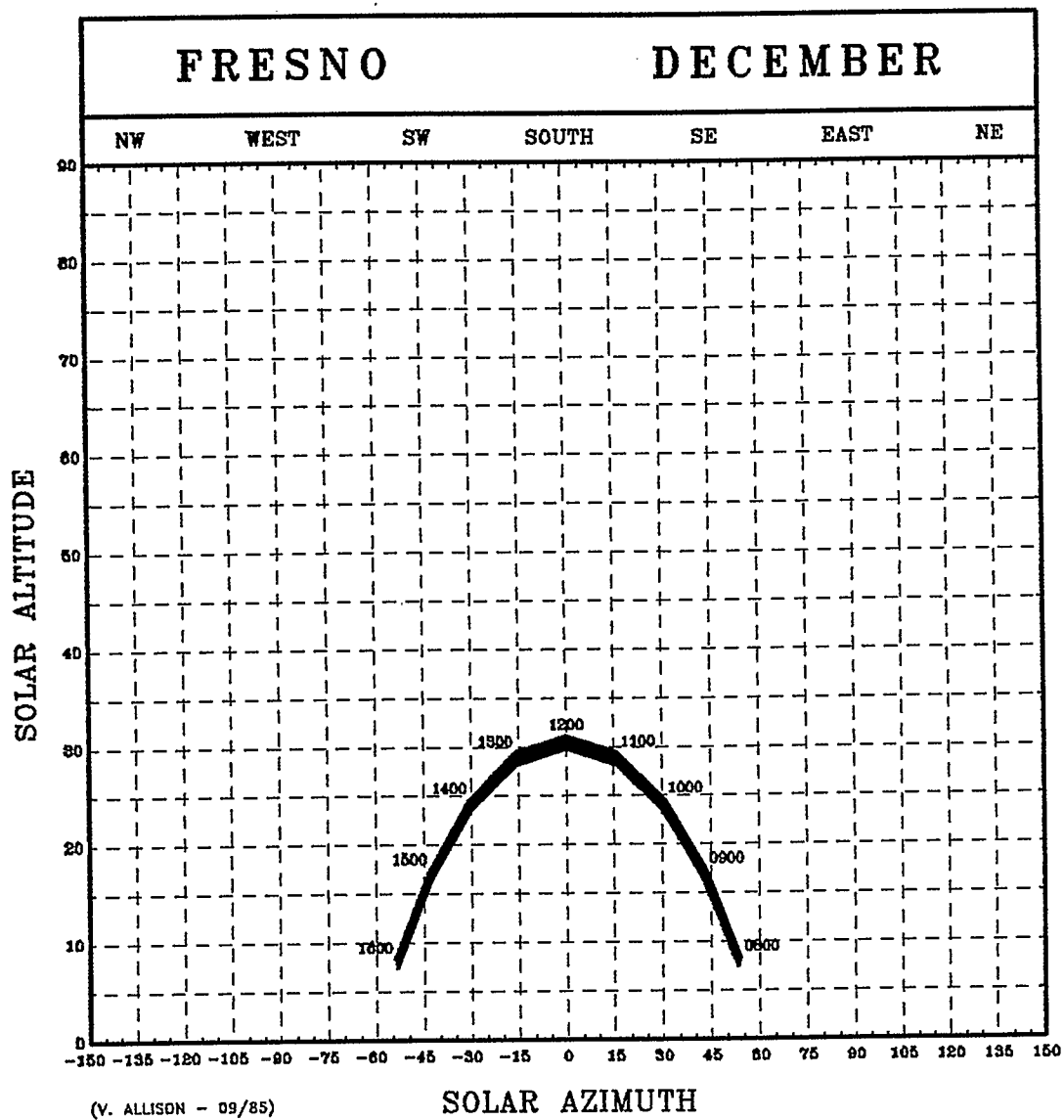




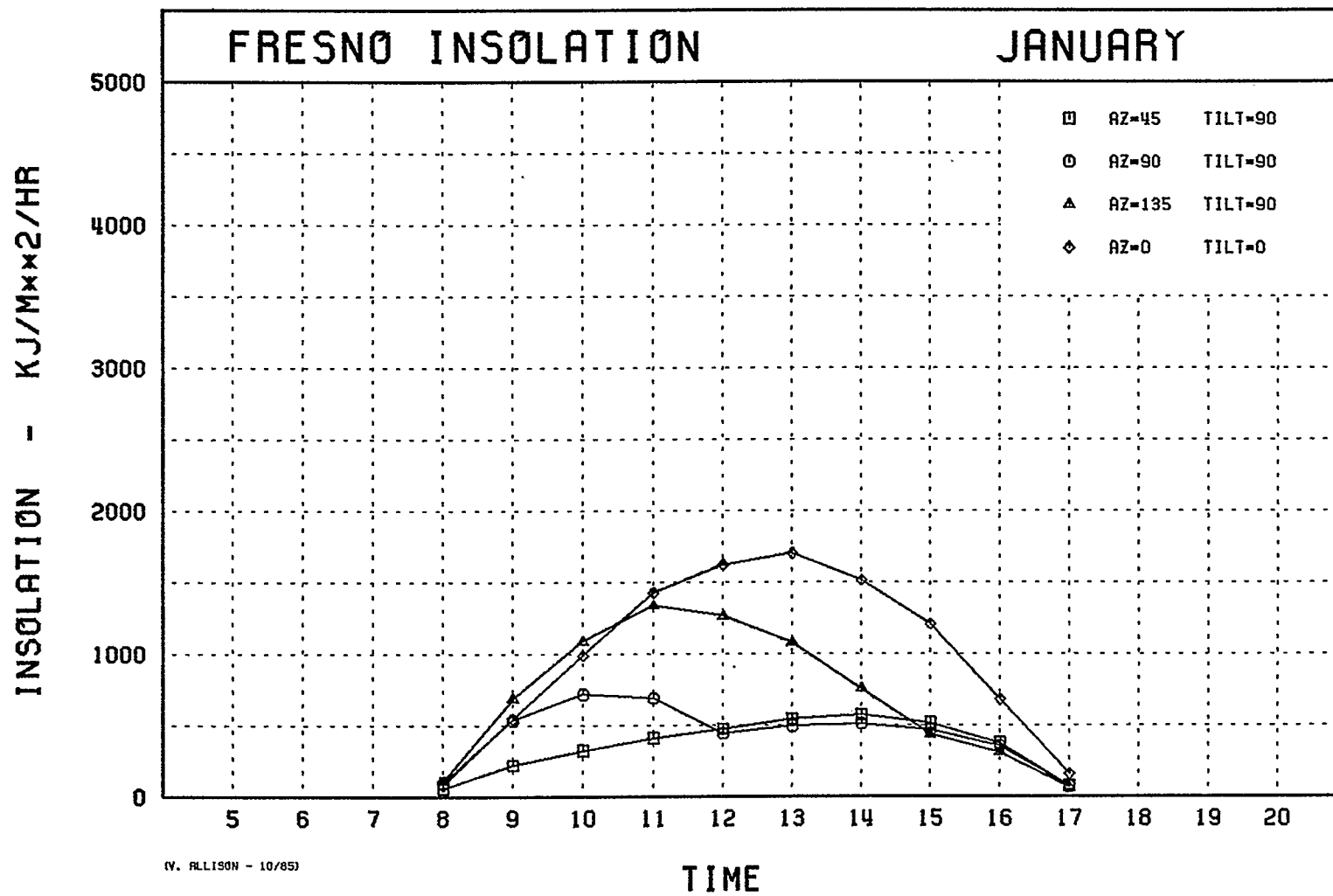


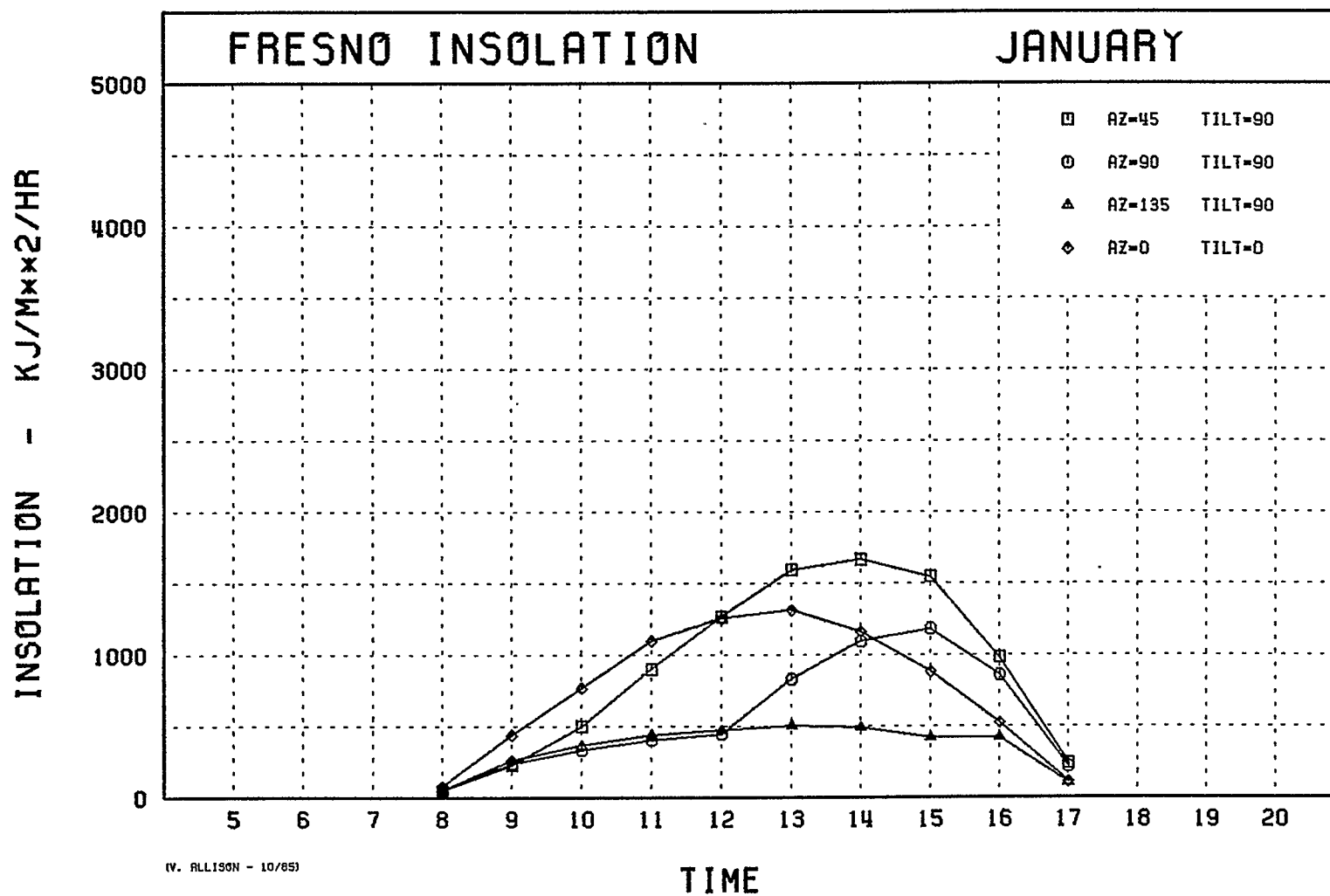


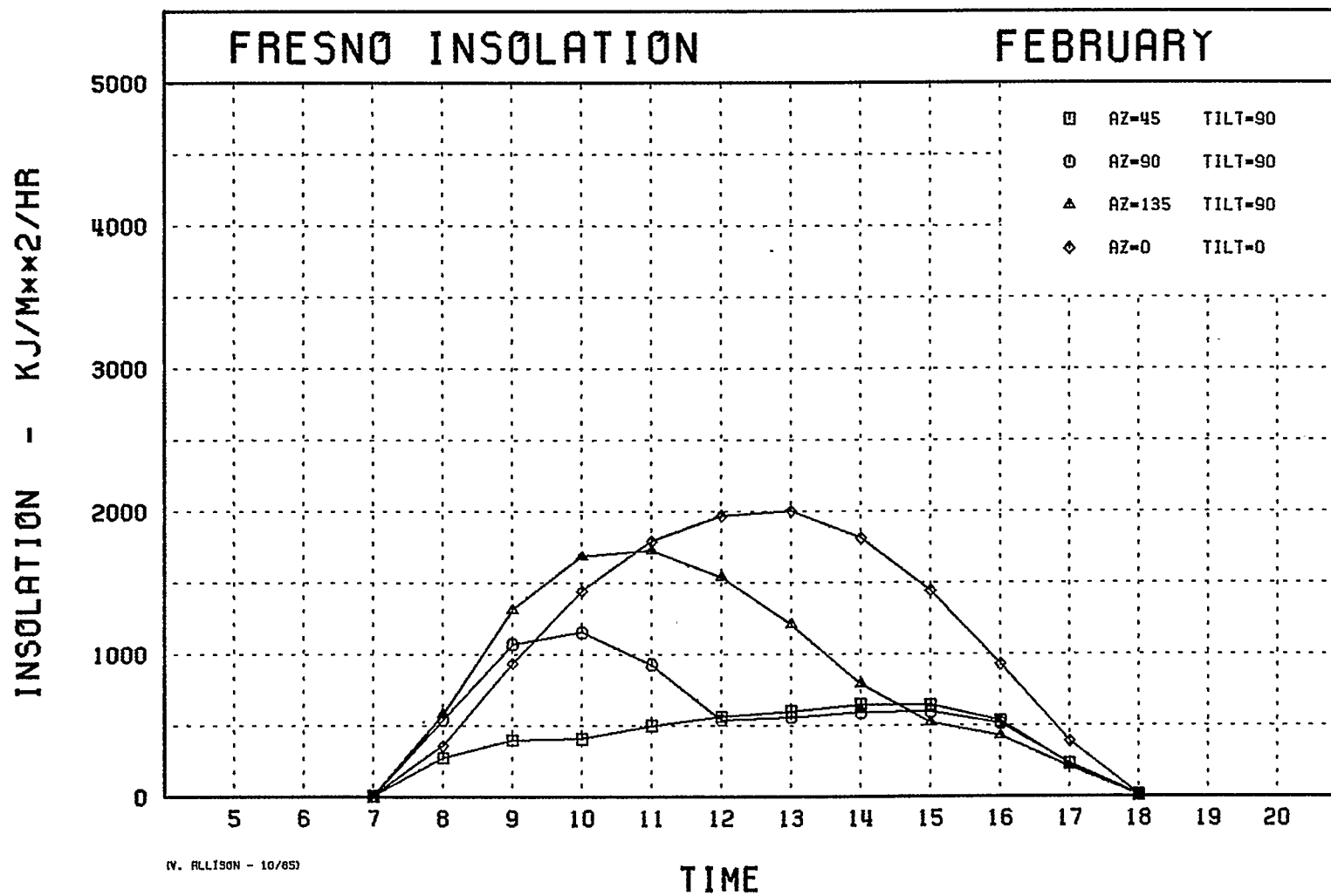


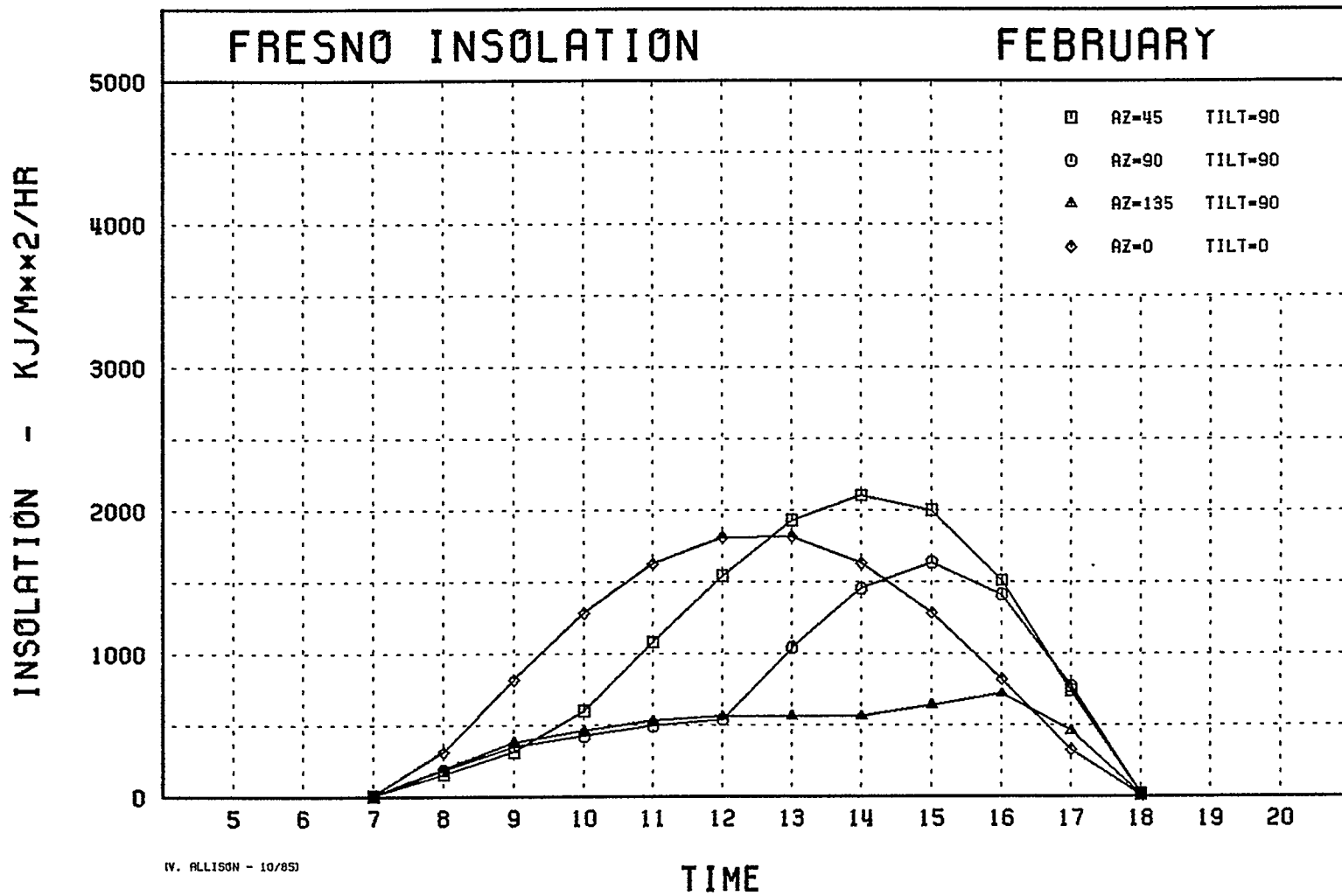


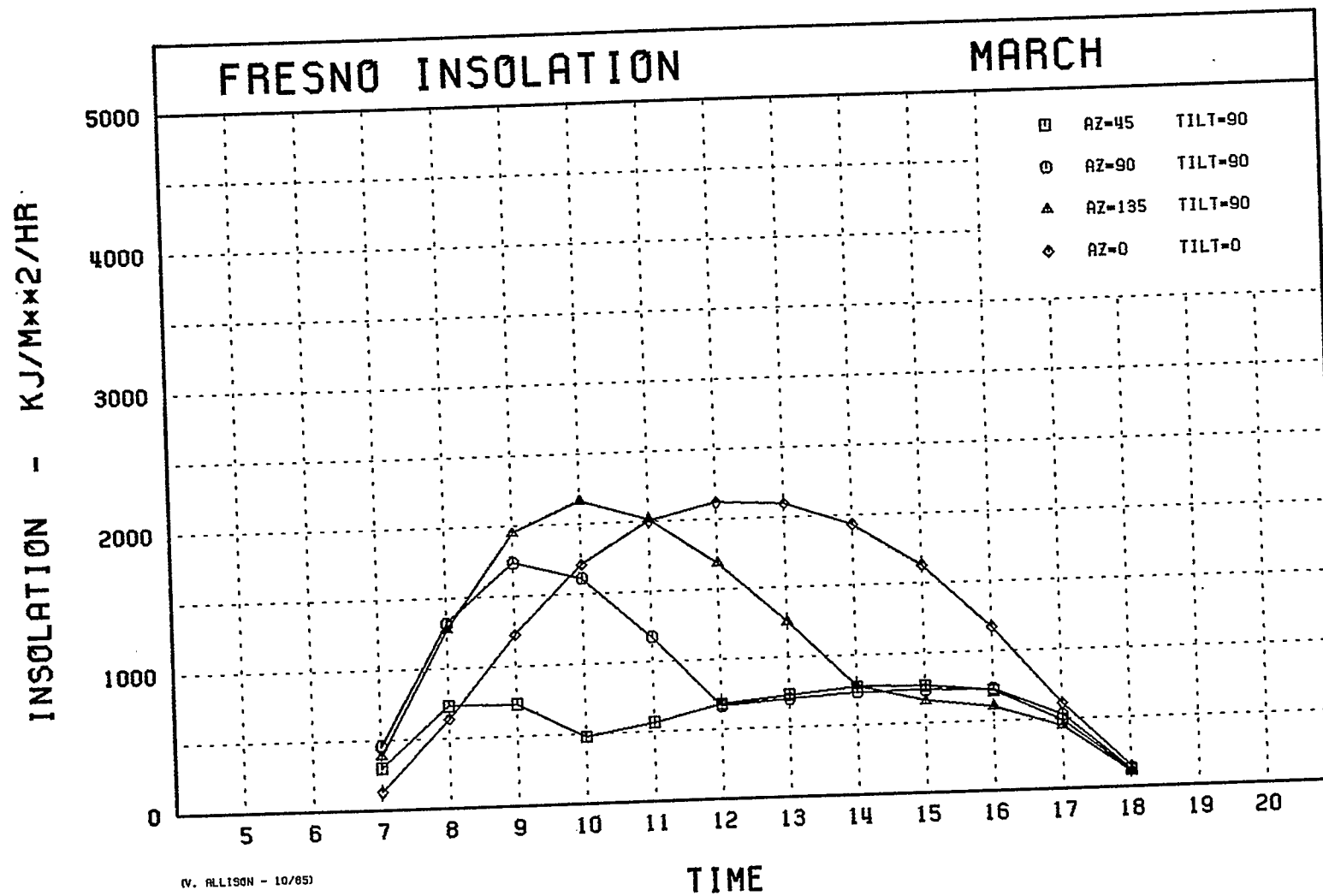
16. APPENDIX 7 - INSPLOT OUTPUT .

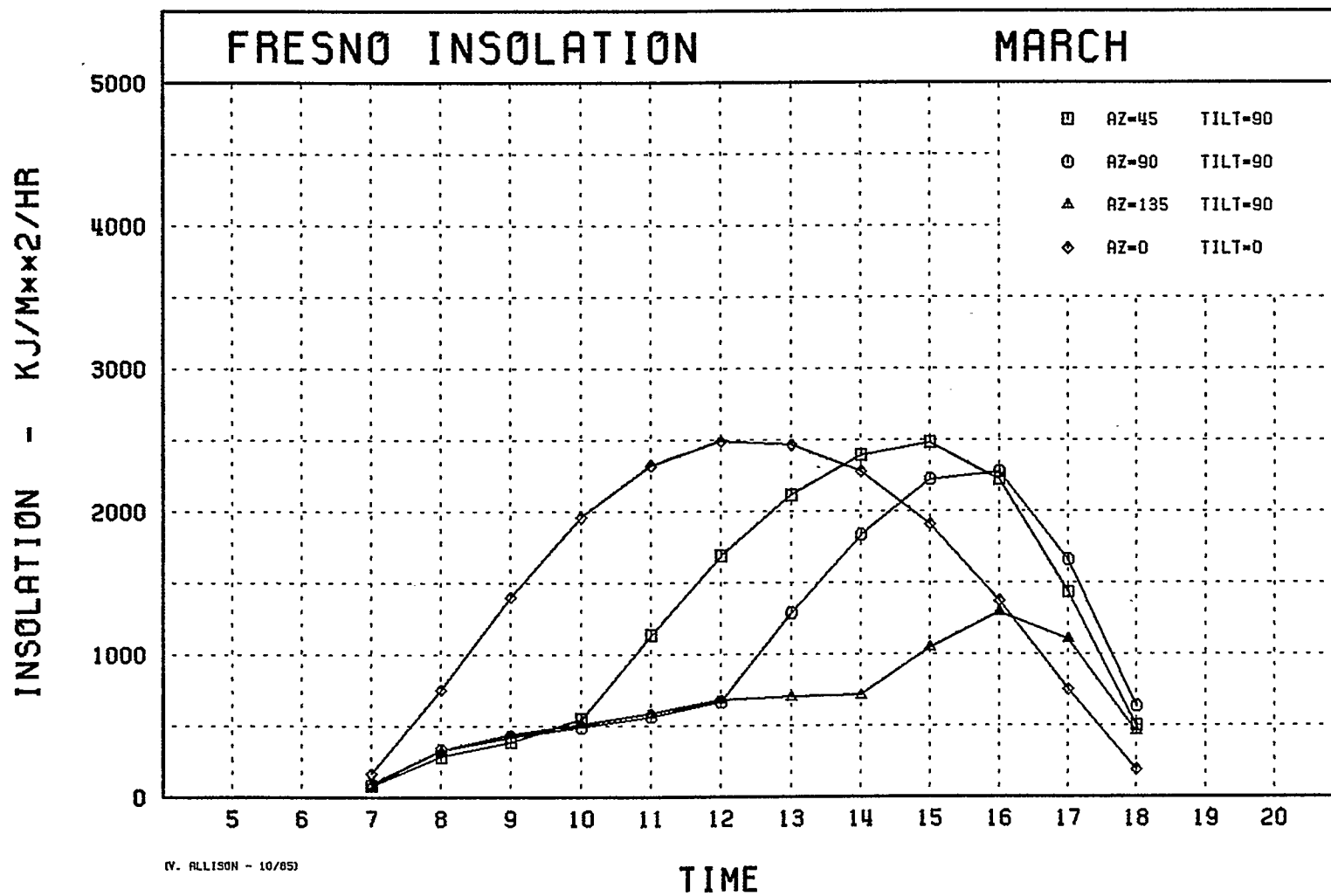


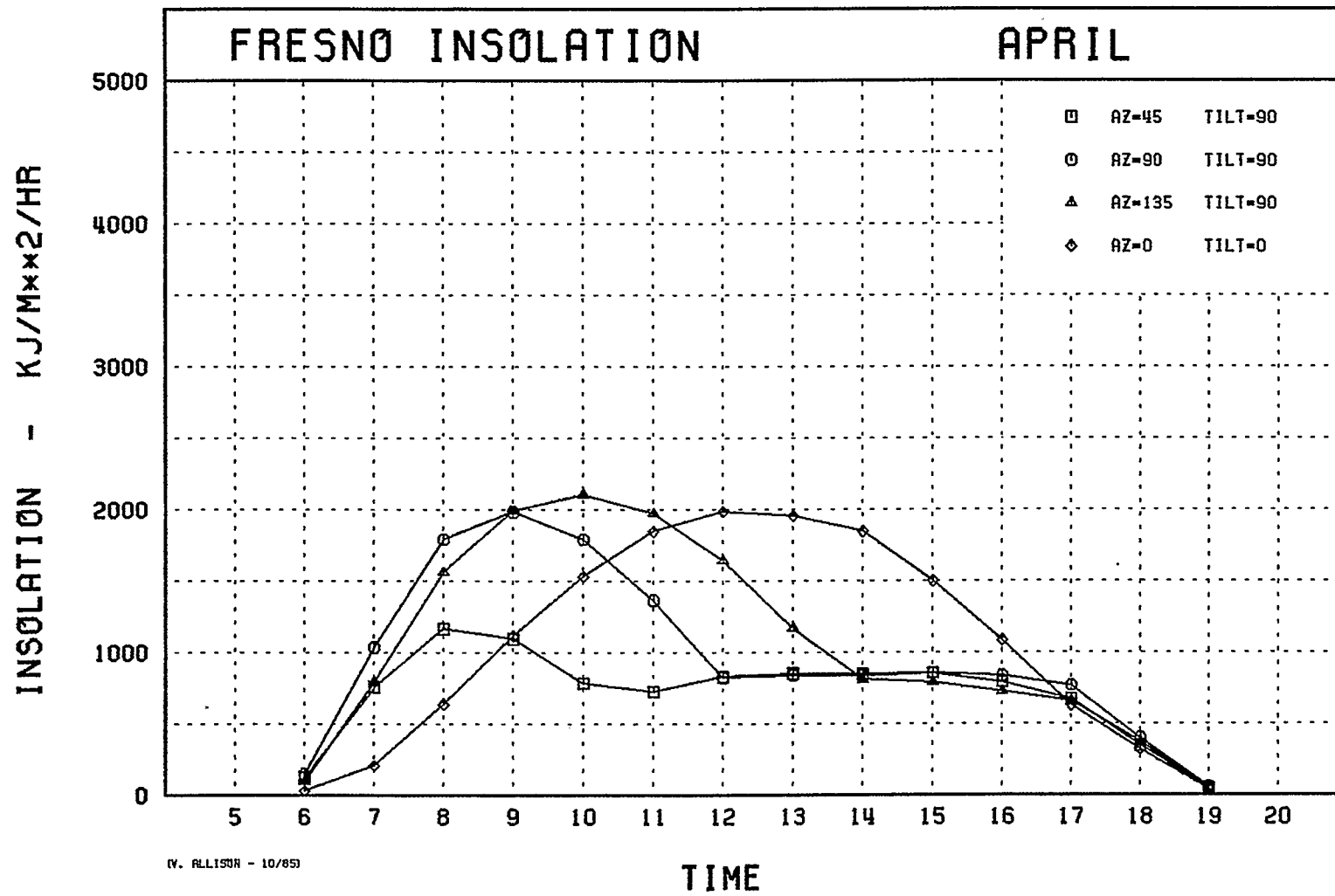


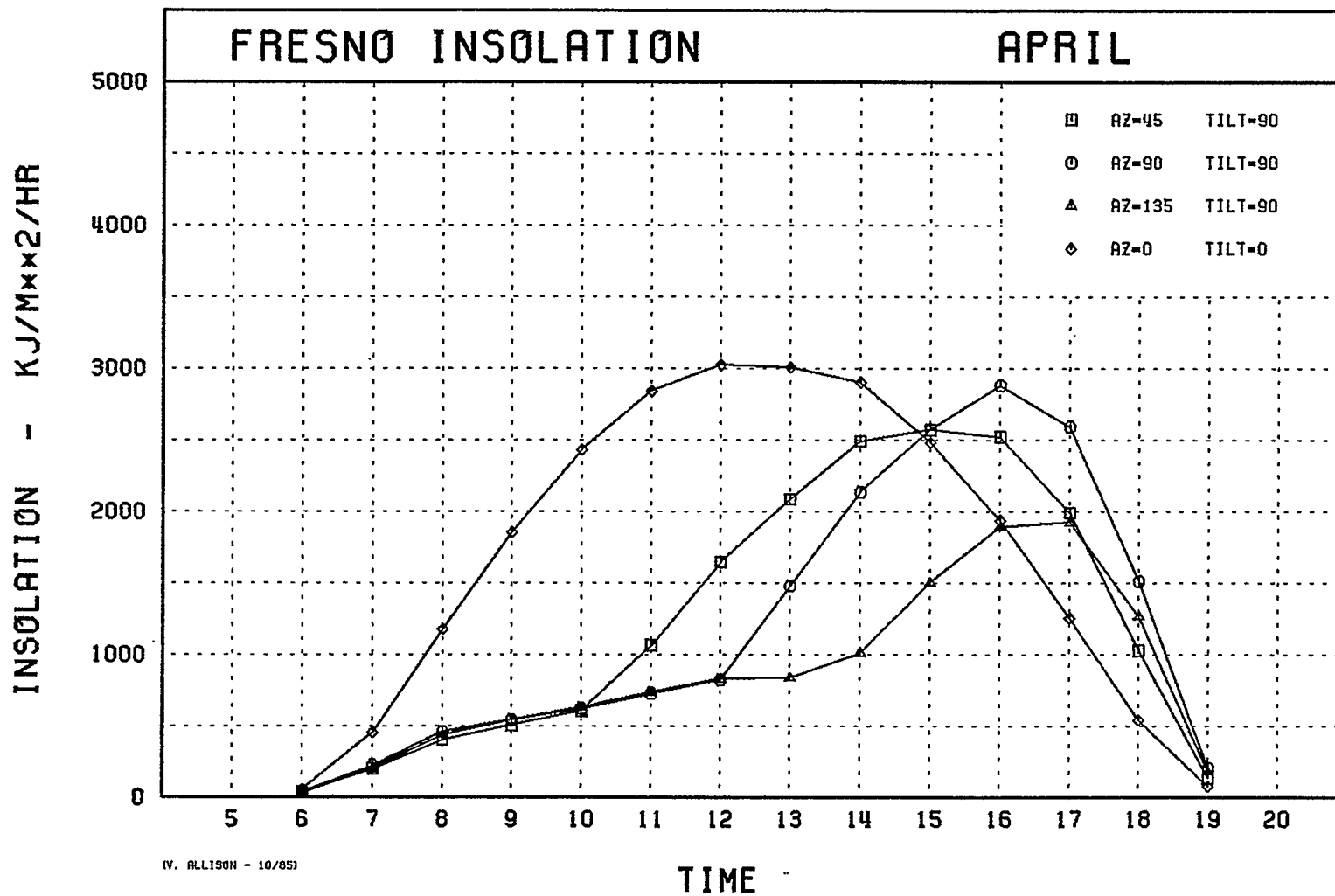


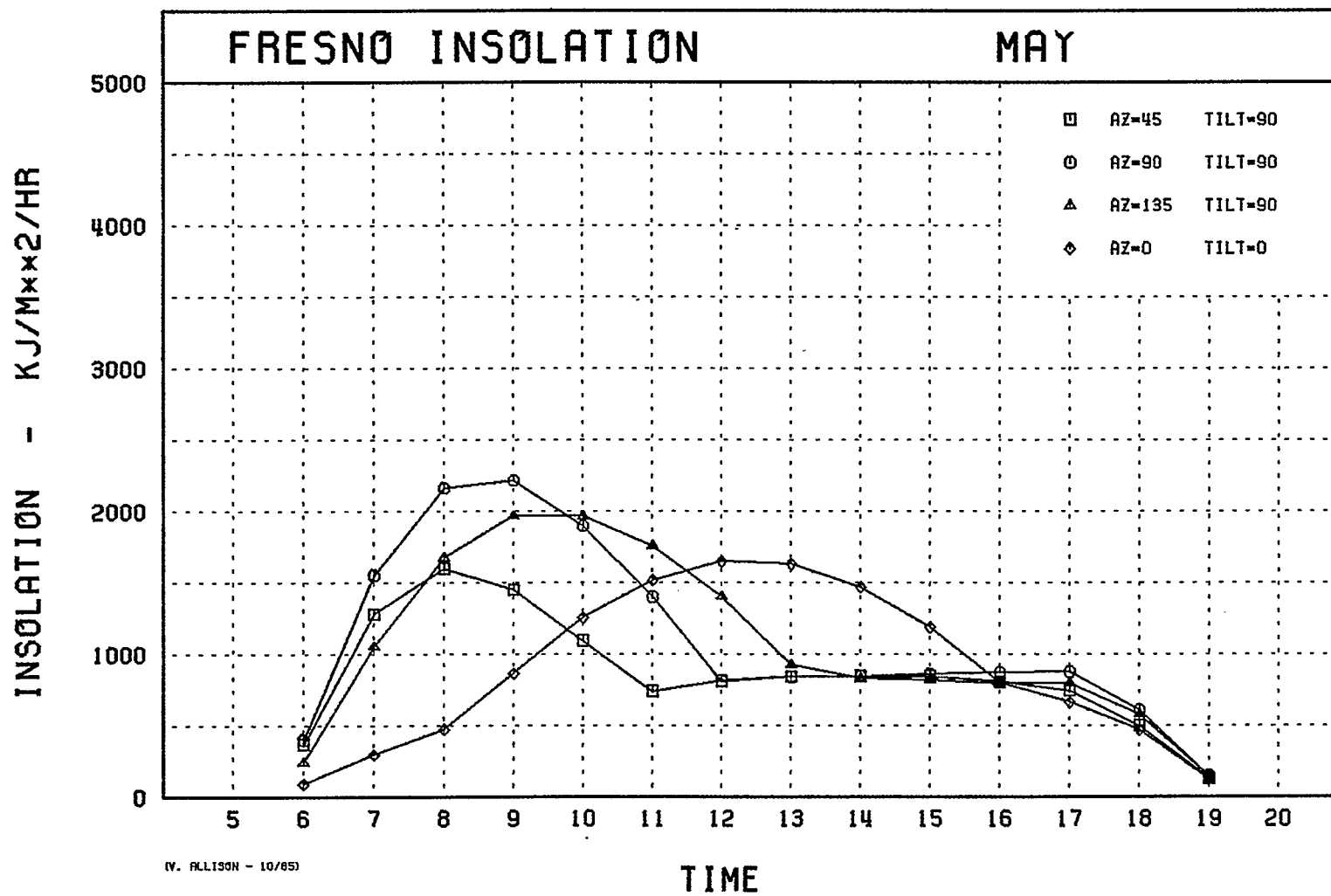


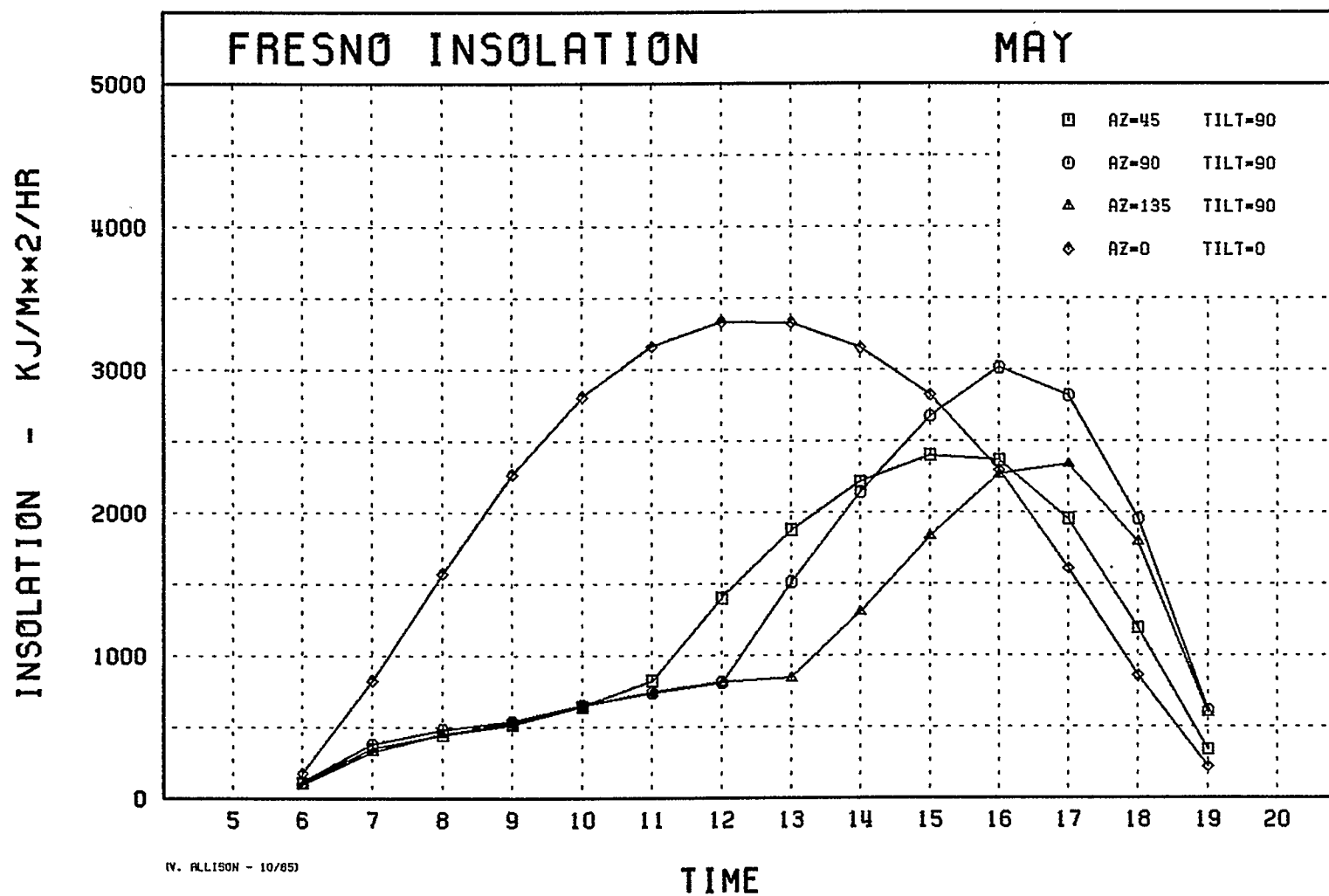


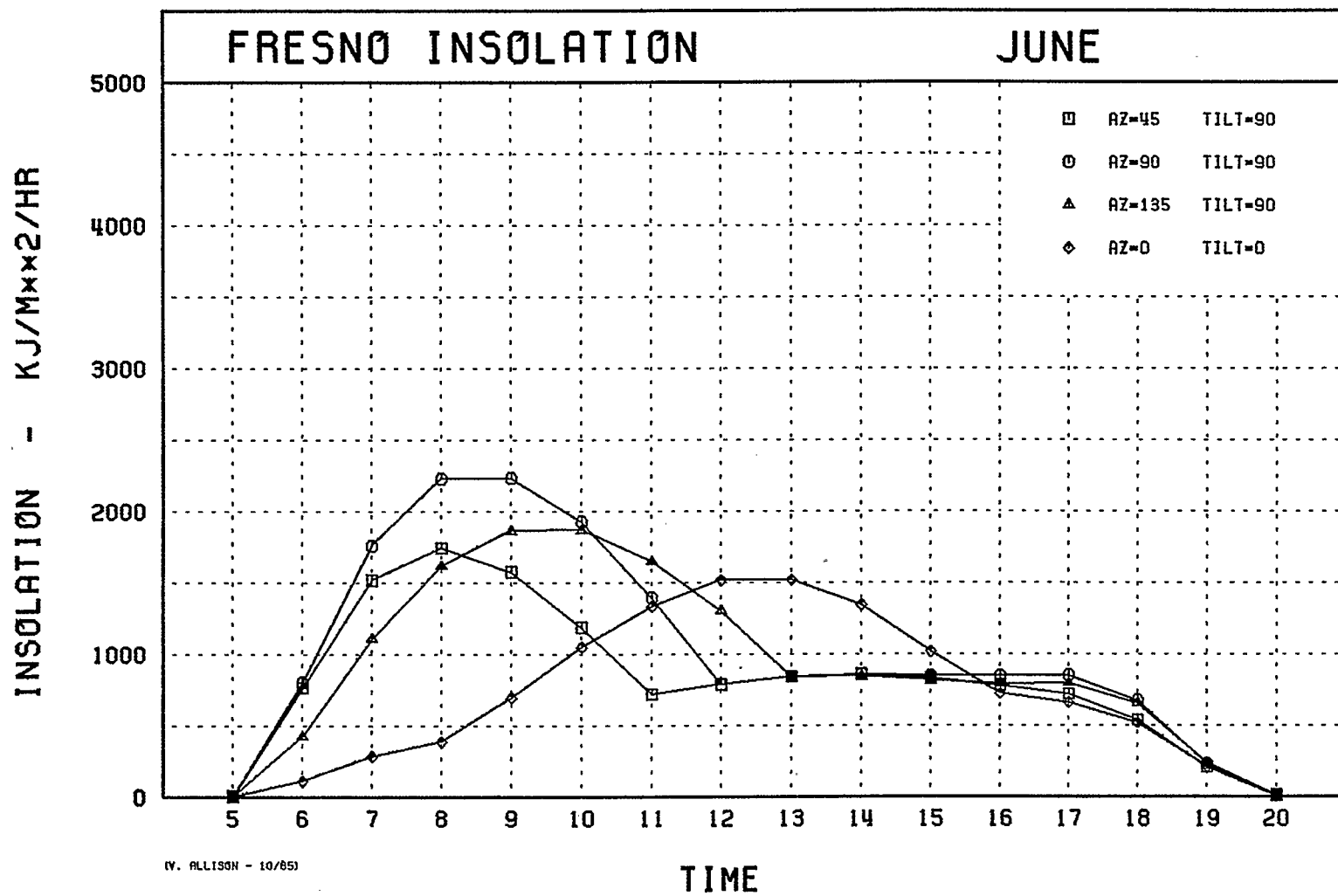


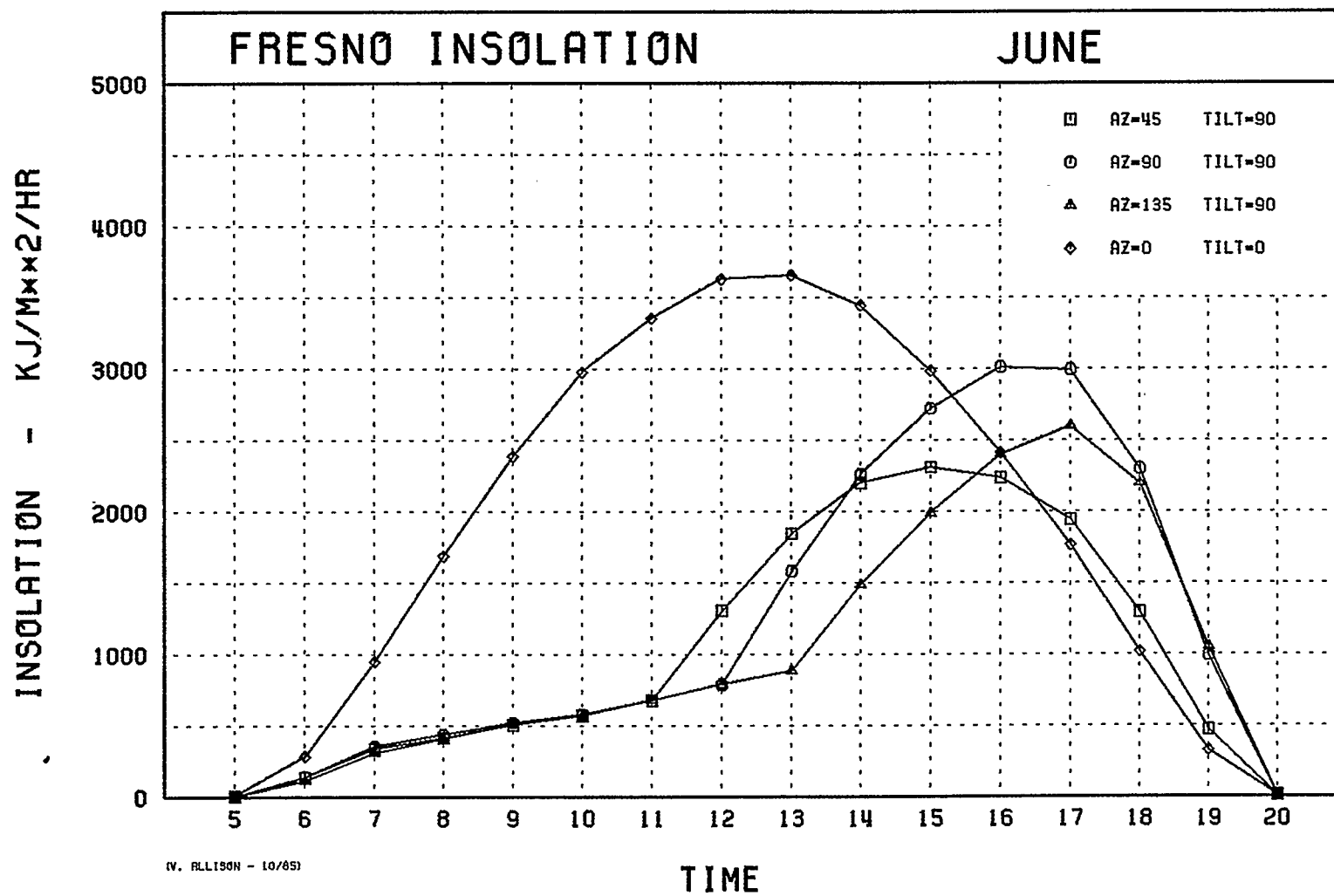


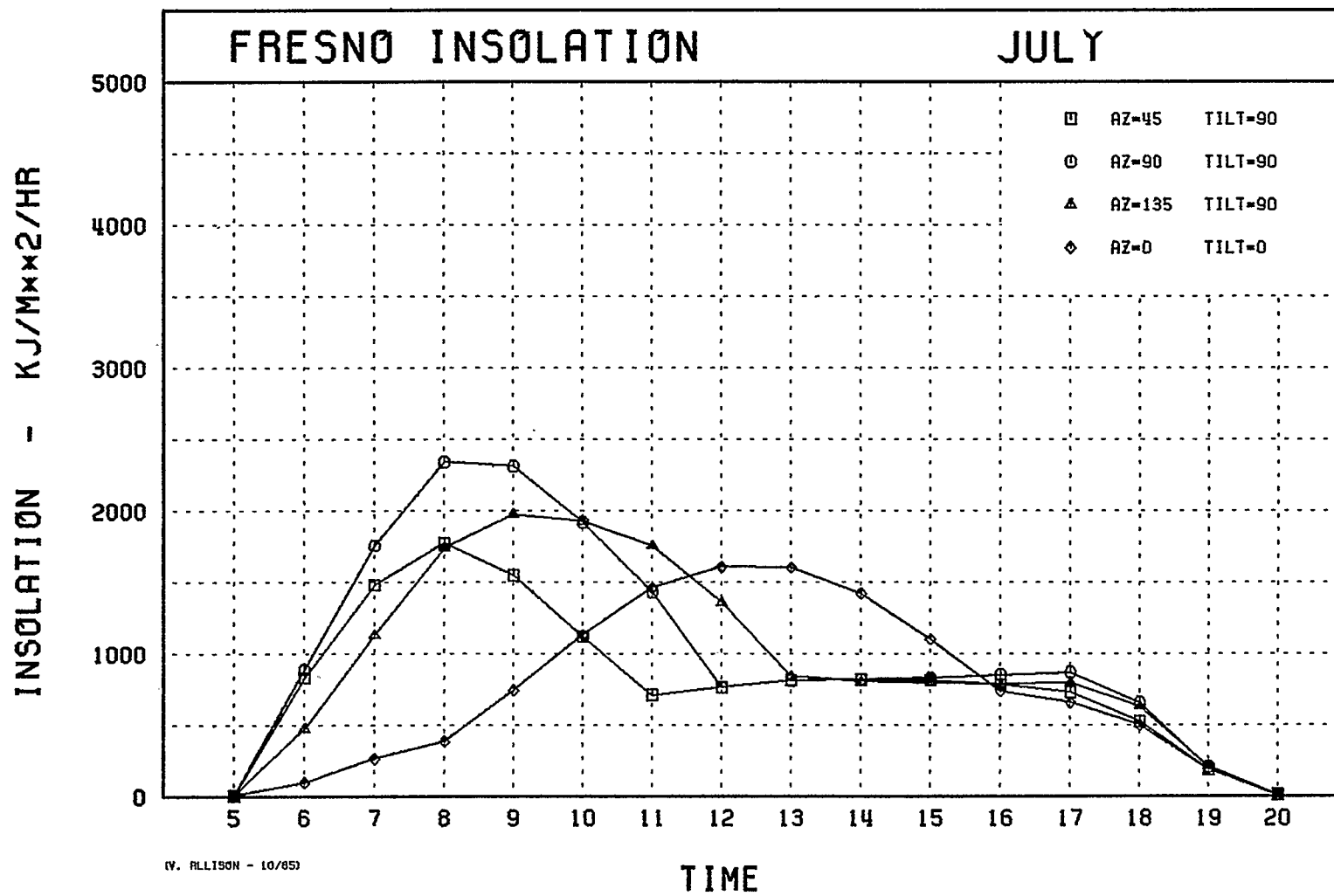


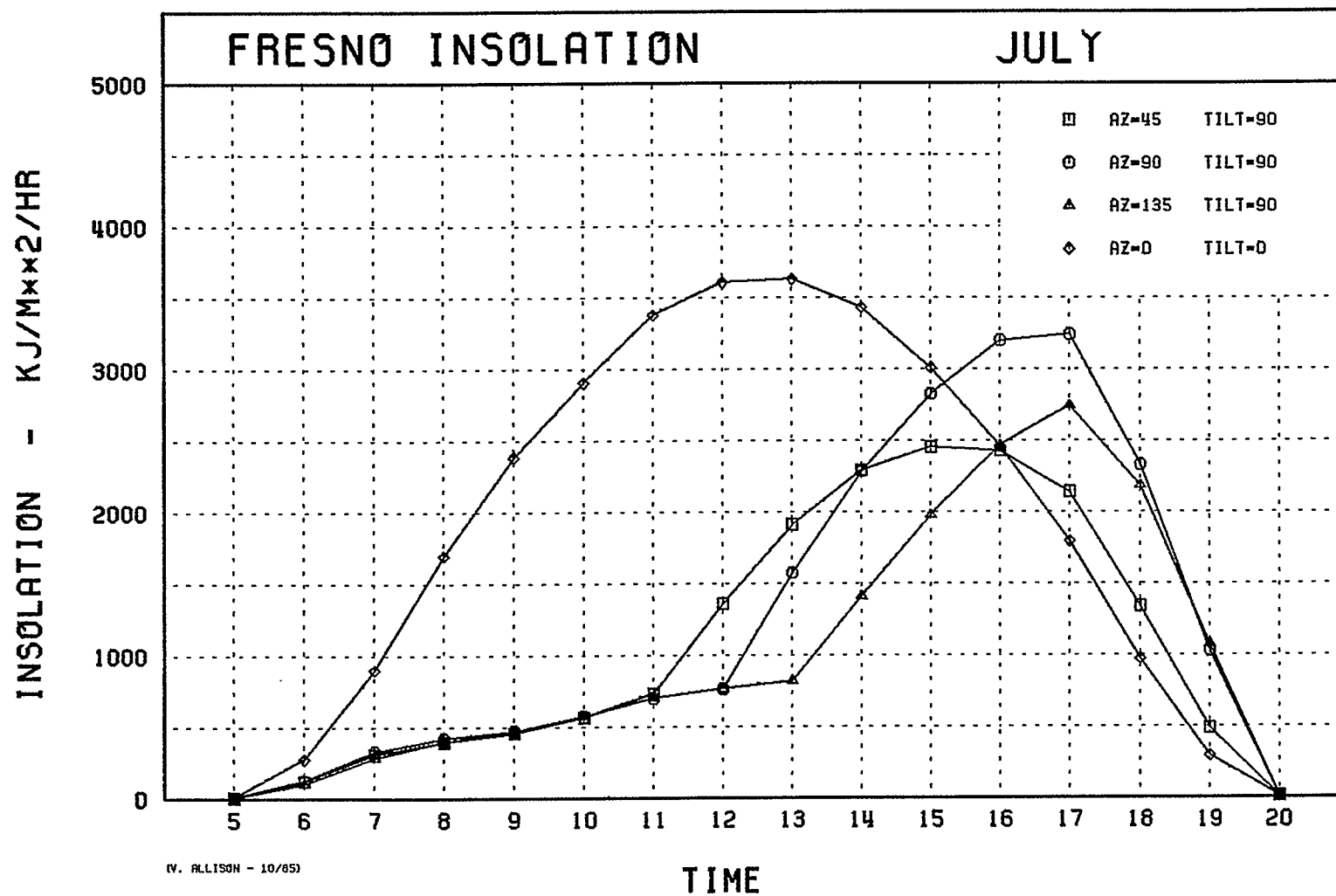


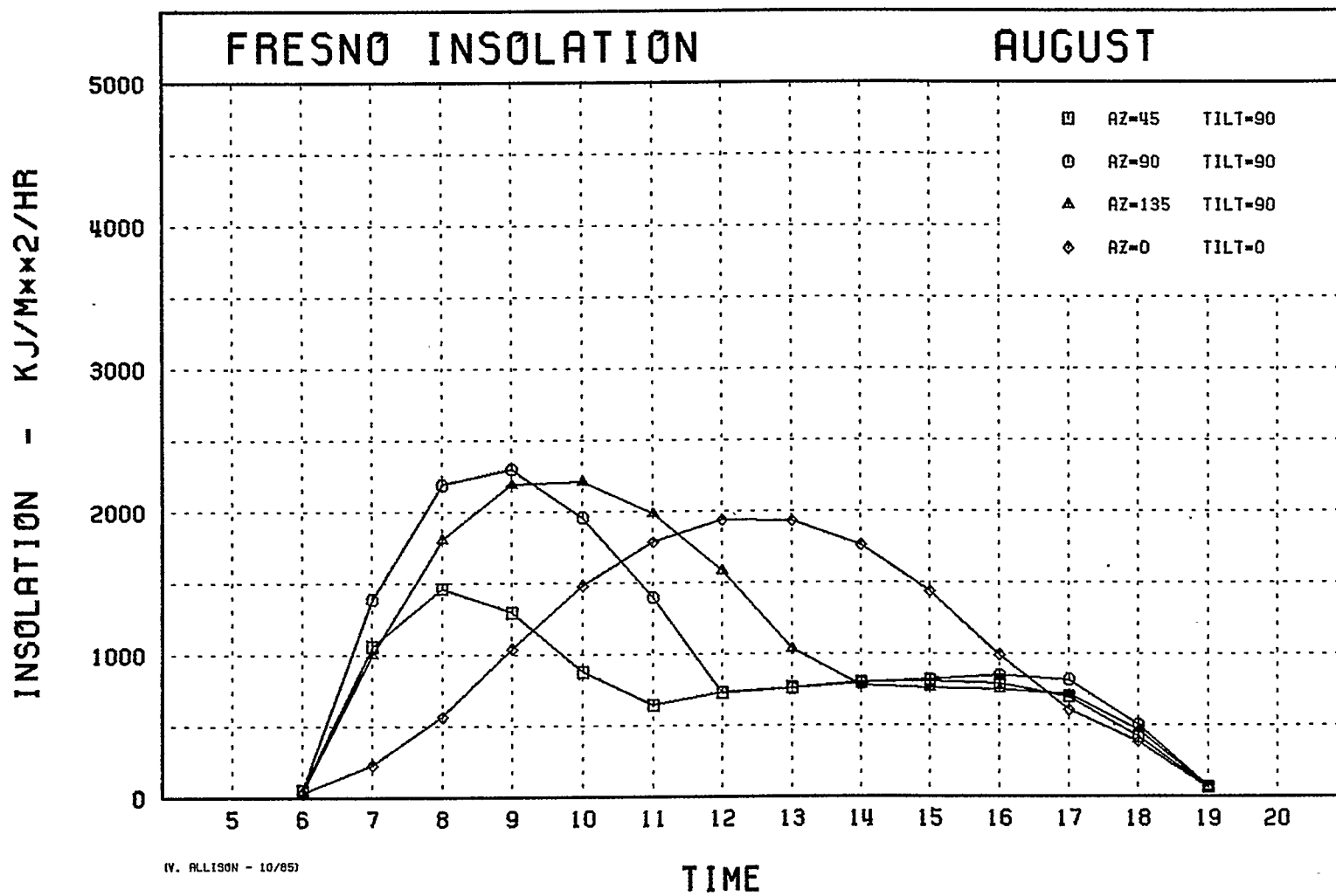


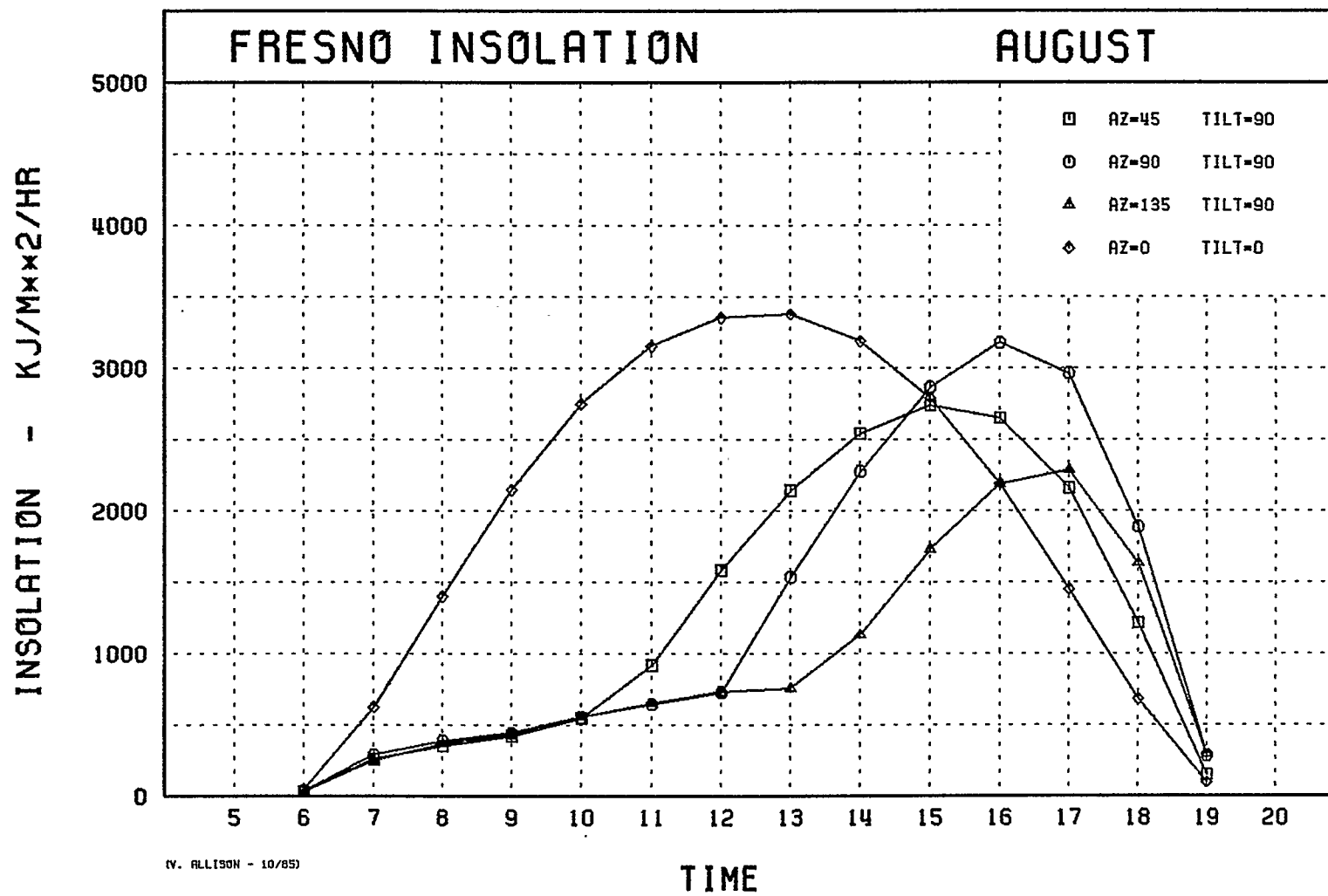


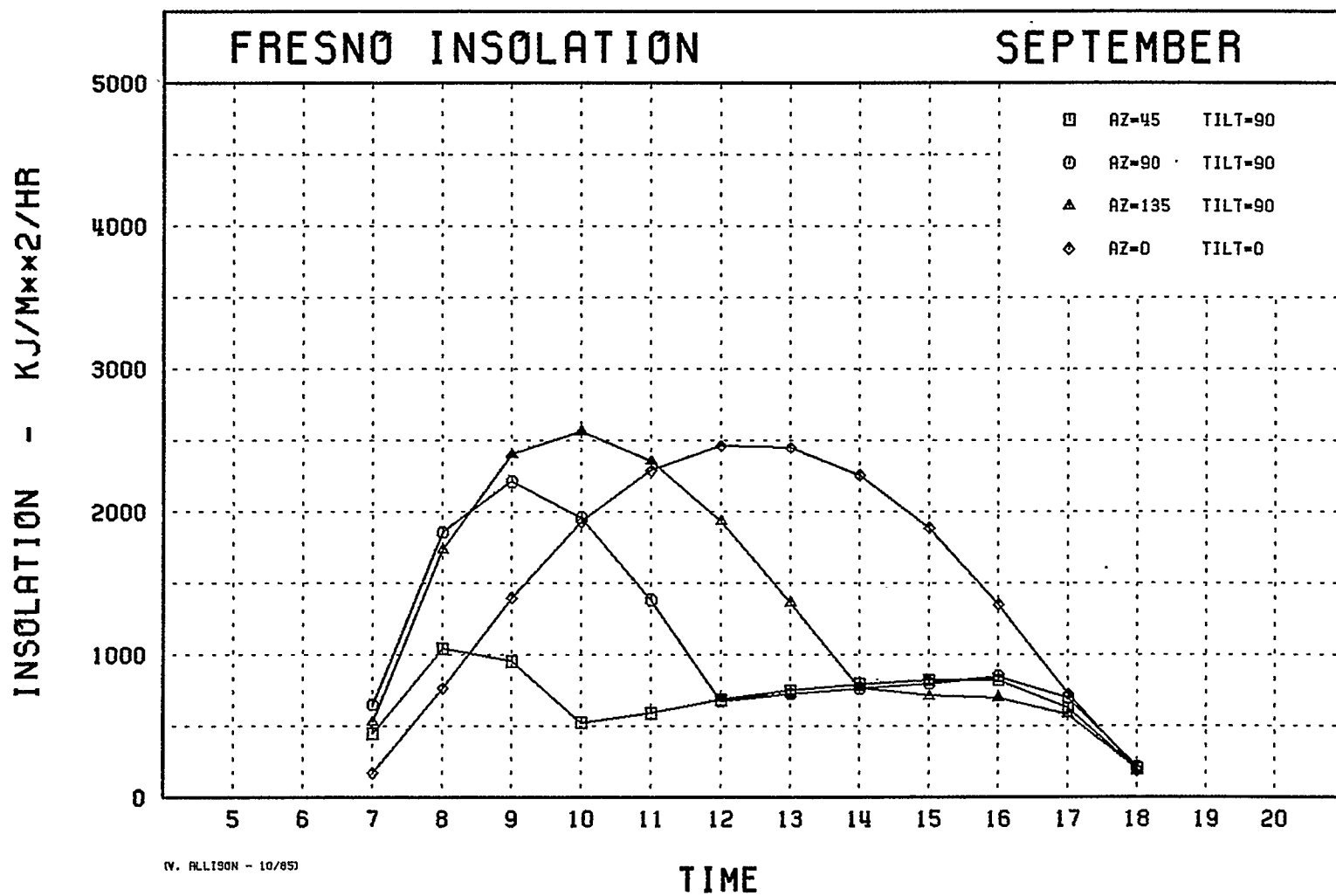


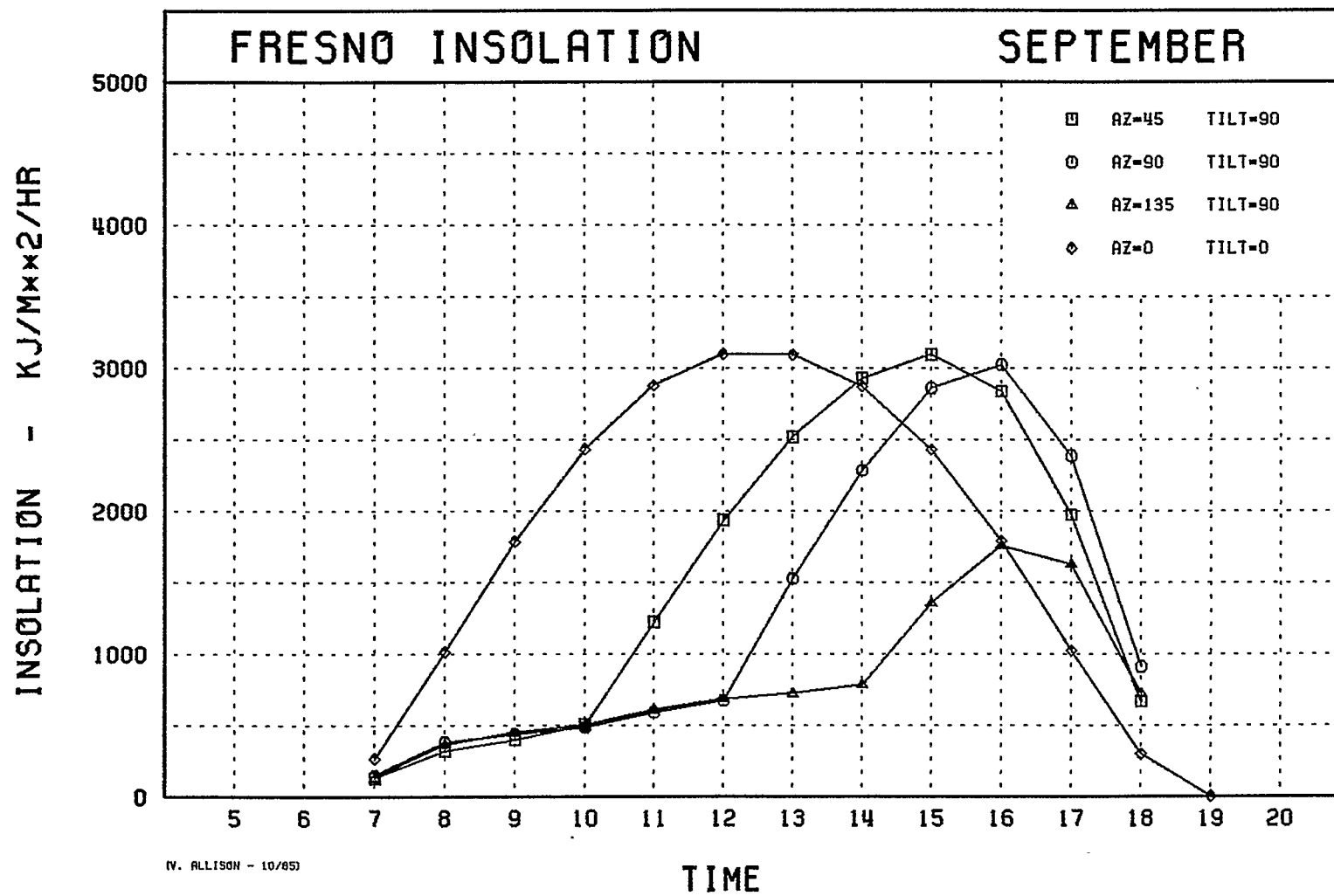


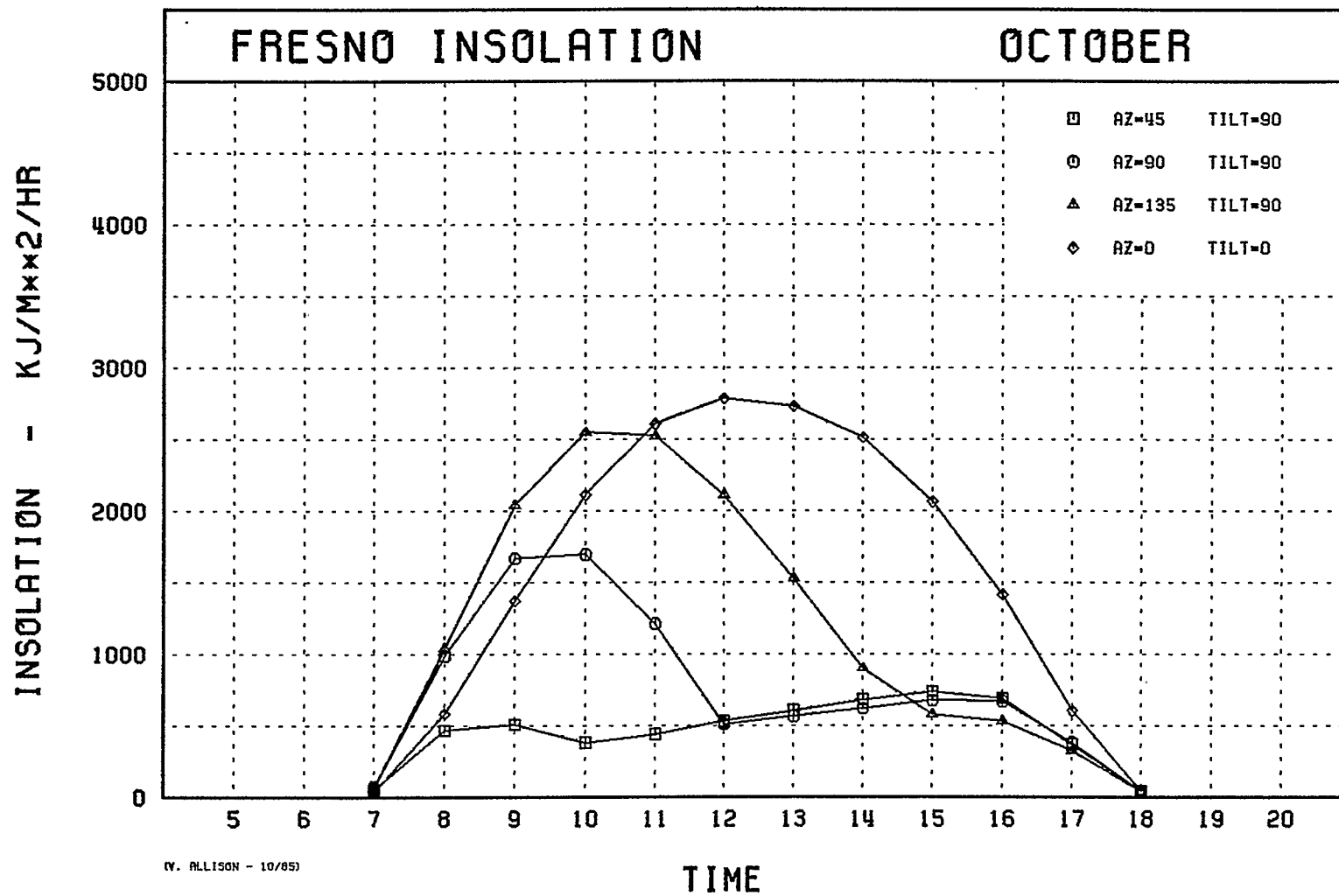


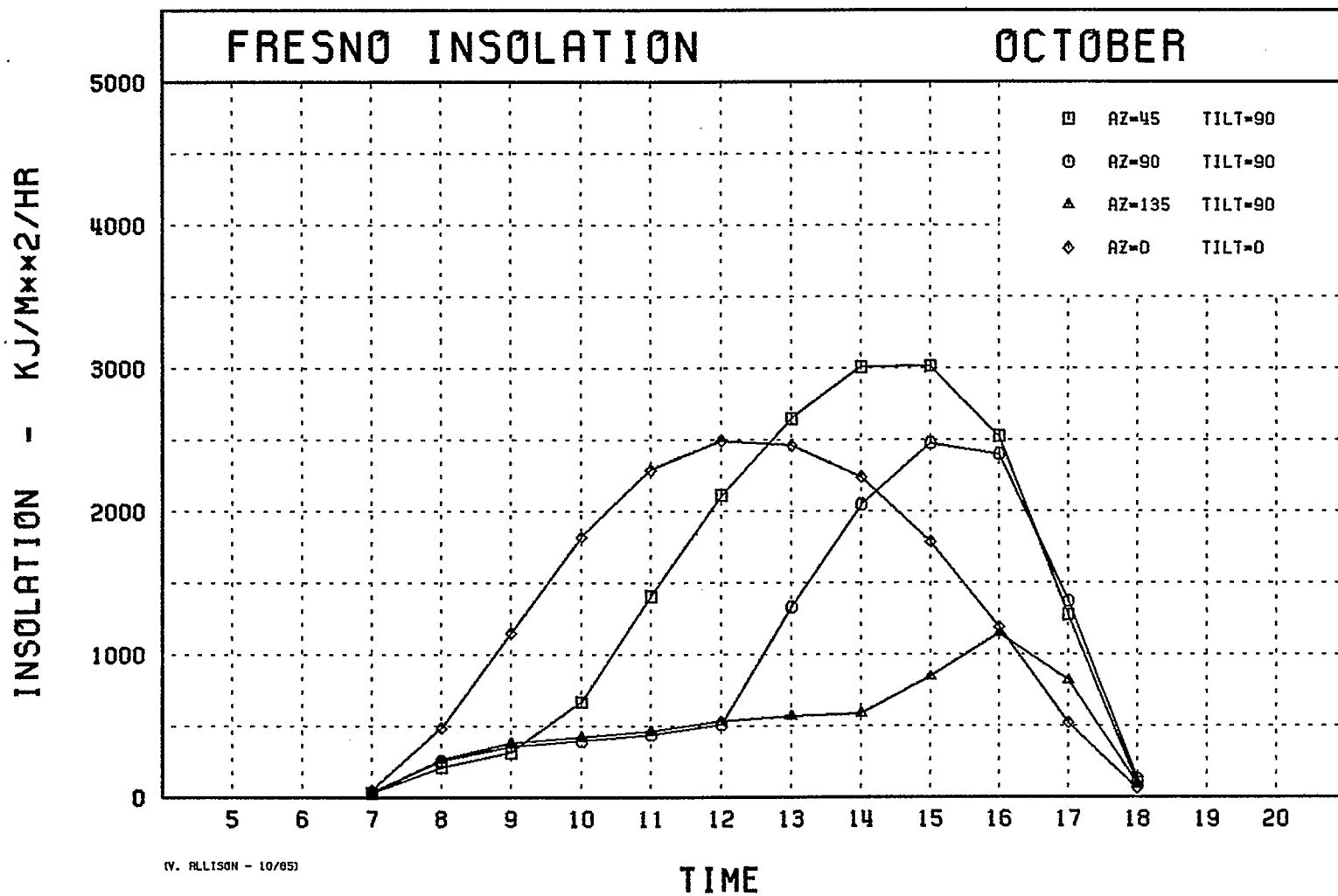


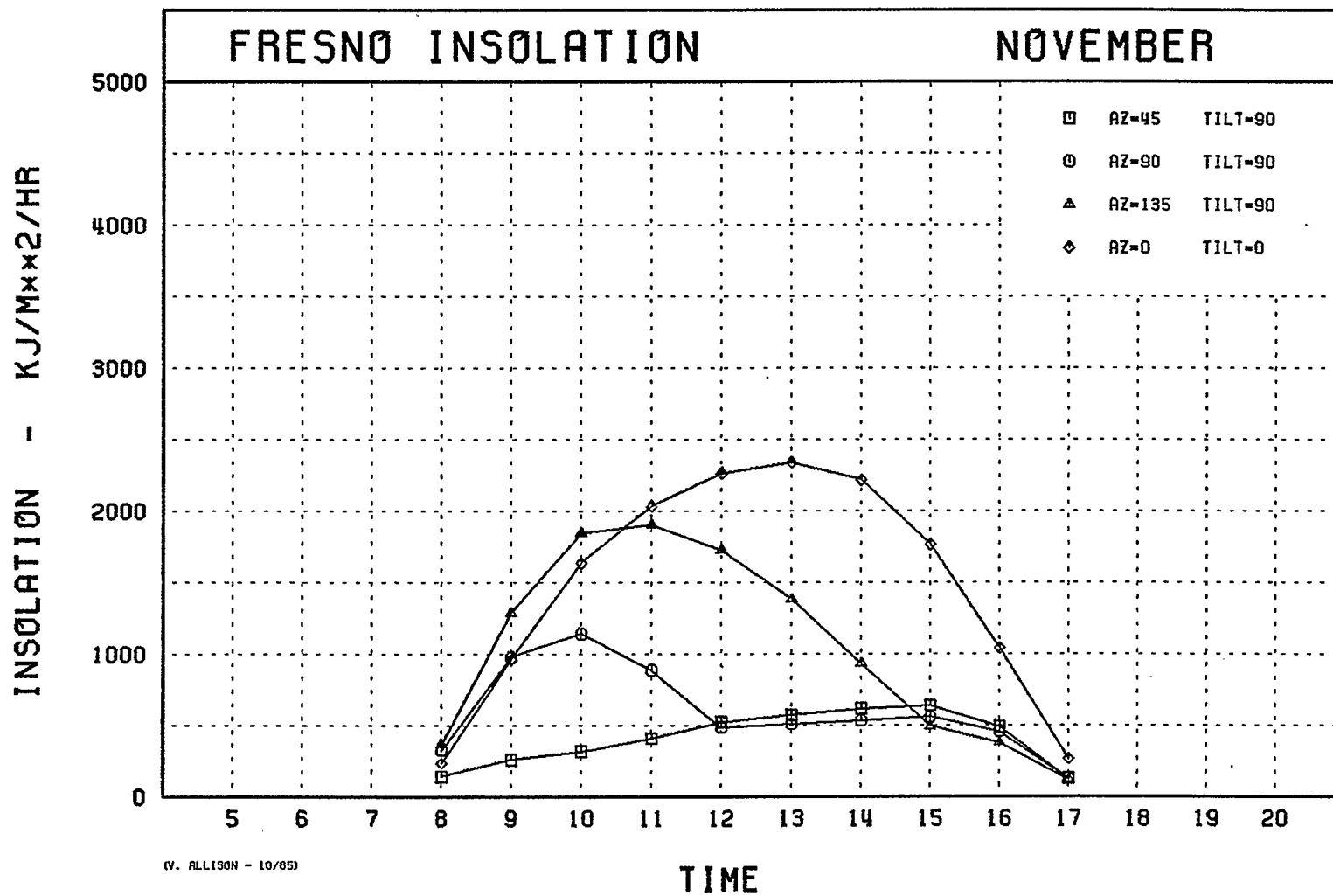


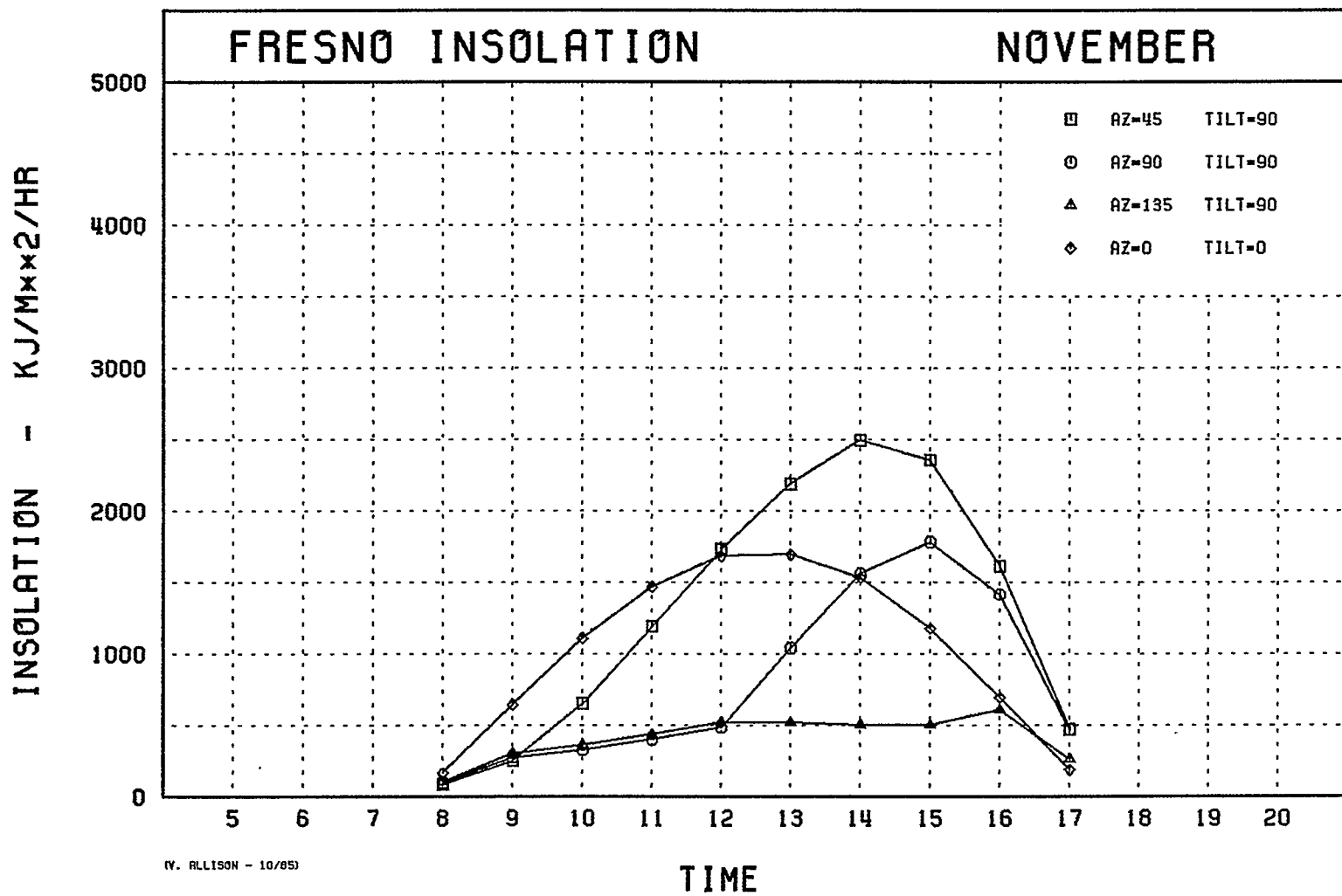


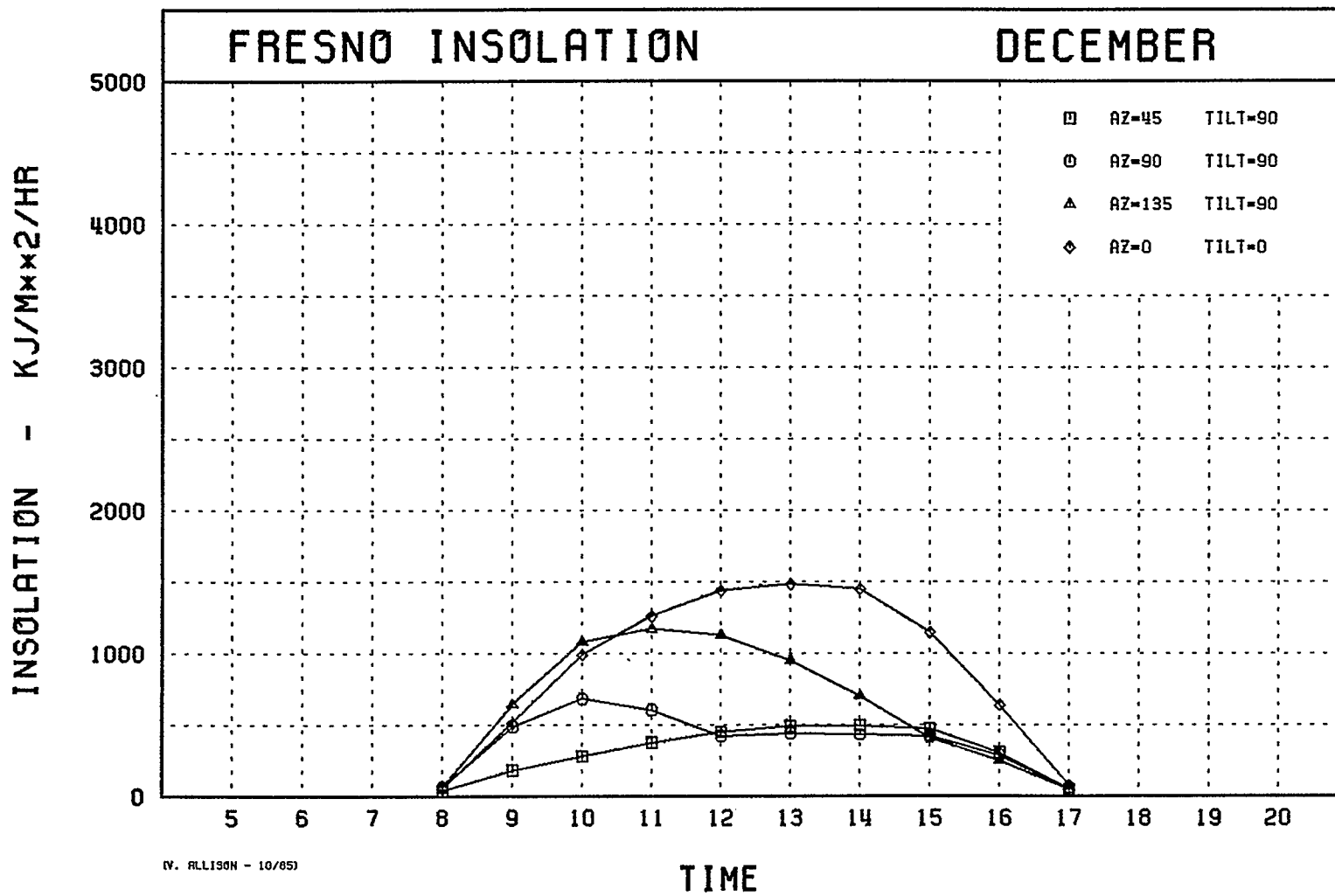


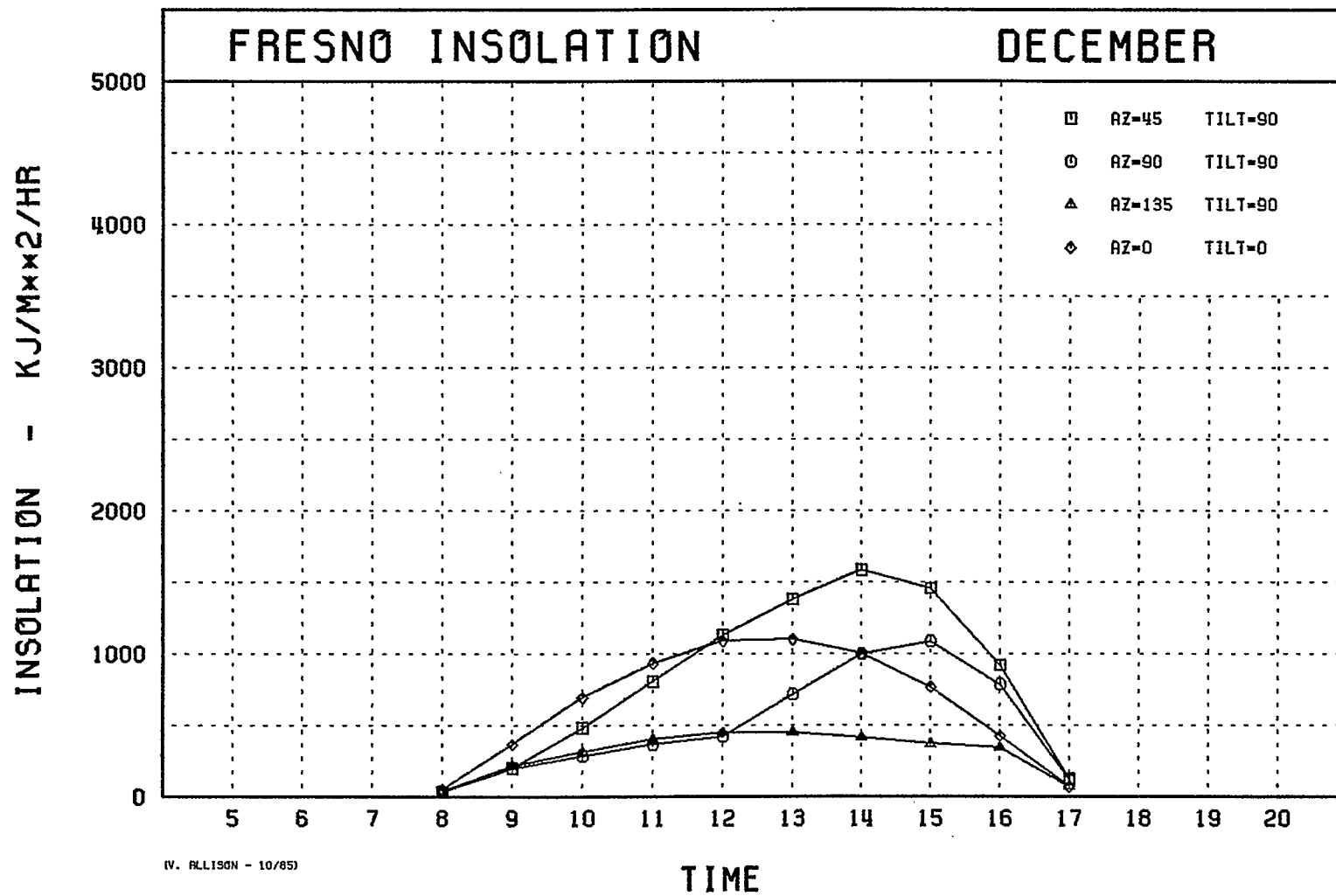












17. APPENDIX 8 - SPREADSHEET OUTPUT

```

*****
*           B A L A N C I N G           *
*                                           *
*   C O N S E R V A T I O N   A N D   S O L A R   *
*****
          *
        ***
        *****
        *****

```

LOTUS 1-2-3 Spreadsheet by Victor Allison - c November 1985

Reference: Passive Solar Design Handbook
Total Environmental Action, Inc. /
Los Alamos Scientific Laboratory /
Los Alamos National Laboratory
New York: Van Nostrand Reinhold Co., 1984.

General Notes:

The user of this spreadsheet must have access to the Passive Solar Design Handbook (or similar) to reference SSF and CF Tables.

SSF = 0.10 corresponds to a threshold passive solar building.
SSF = 0.50 corresponds to a typical passive solar building.
SSF = 0.80 corresponds to a major solar building.

All calculated parameters are surrounded by asterisks like this:

```

*****
Parameter = xxx.yy
*****

```

All parameters not surrounded by asterisks must be entered by the user.

Follow the instructions listed in Blocks 1 - 14.

-
- 1 - Select an initial Solar Savings Fraction (SSF) for the design and enter it under Selected SSF.
Enter 0.1 or 0.5 for the Lower Bound SSF and 0.5 or 0.8 for the Upper Bound SSF.

Lower Bound SSF		Selected SSF		Upper Bound SSF
0.10	<=	0.25	<=	0.50

- 2 - Enter the selected System Designation(s) and their Area Weighting(s)
Enter 0.0 for unused systems.
- 3 - From the Conservation Factor (CF) table enter those CF's whose SSF's form the lower and upper bounds of the selected SSF, i.e. lower SSF <= selected SSF <= upper SSF.

System Design	Area Weight CF	Lower SSF CF	Selected SSF CF	Upper SSF CF
SS xx	0.00	0.00	0.00	0.00
DG B1	1.00	1.00	1.19	1.50
WW xx	0.00	0.00	0.00	0.00
TW xx	0.00	0.00	0.00	0.00

Area Weighted Average CF = 1.19

-
- 4 - Price the costs for 2 wall systems in \$ per sq. metre using different RSI values (e.g. $RSI_2 = 2 \times RSI_1$) and enter the values under \$/sqm.
- 5 - Repeat for Floors, Ceiling, heated Basement, Perimeter, Glazing and Infiltration.
 Use Floors for unheated crawlspace.
 Use Perimeter for slab-on-grade.
 Use Basement for heated basement or other fully bermed wall, including floor losses.
 Enter 0.0 under the cost and a dummy value under RSI for unused constructions.

	RSI	\$/sqm
	----	----
Wall 1	1.9	32.29
Wall 2	6.3	45.75

 Incremental Cost of Wall Insulation = \$3.05 /RSI/sqm

	RSI	\$/sqm
	----	----
Ceiling 1	5.3	21.53
Ceiling 2	10.6	31.22

 Incremental Cost of Ceiling Insulation = \$1.83 /RSI/sqm

	RSI	\$/m
	-----	-----
Perimeter 1	3.5	6.56
Perimeter 2	7.1	22.97

Incremental Cost of Perimeter Insulation = \$4.66 /RSI/m

	RSI	\$/sqm
	-----	-----
Floor 1	1.8	0.00
Floor 2	2.6	0.00

Incremental Cost of Floor Insulation = \$0.00 /RSI/sqm

	RSI	\$/m
	-----	-----
Perimeter 1	3.5	0.00
Perimeter 2	7.1	0.00

Incremental Cost of Basement Insulation = \$0.00 /RSI/m

	RSI	\$/sqm
	-----	-----
Glazing 1	0.11	53.82
Glazing 2	0.28	96.88

Incremental Cost for One Added Glazing = \$43.06 /sqm
\$246.06 /R/sqm

	ACH	\$/cum
	-----	-----
Infiltr 1	1.00	3.43
Infiltr 2	0.75	3.71

Incremental Cost for Infil. Decrease = \$1.12 /(1/ACH)/cum

-
- 6 - Estimate the cost of the sunspace in \$ per sqm of glazing and enter it.
Enter 0.0 if there is no sunspace.

Feature	\$/sqm
-----	-----
Sunspace	0.00

-
- 7 - Determine a reasonable estimate of the sunspace amenity (appraisal) value and enter it.
This value should be less than that of the Block 6.
Enter 0.0 if there is no sunspace.

	\$/sqm

Sunspace	0.00

-
- 8 - Enter the sunspace's Total Glazed Area and Projected Area.
Enter 1.0E+99 if there is no sunspace.

Total Glazed Area =	*****sqm
Projected Area =	*****sqm

9 - For the other passive features enter the cost of the feature glazing the replaced opaque wall and the moveable insulation (if used). Enter 0.0 for unused features.

Direct Gain Glazing	=	\$96.88 /sqm
Direct Gain Opaque Wall	=	\$33.17 /sqm
Direct Gain Night Insulation	=	\$0.00 /sqm
Water Wall Glazing	=	\$0.00 /sqm
Water Wall Opaque Wall	=	\$0.00 /sqm
Water Wall Night Insulation	=	\$0.00 /sqm
Trombe Wall Glazing	=	\$0.00 /sqm
Trombe Wall Opaque Wall	=	\$0.00 /sqm
Trombe Wall Night Insulation	=	\$0.00 /sqm

Incremental Costs of Passive Solar Features are:

Sunspace	=	\$0.00 /sqm of projected area
Direct Gain	=	\$63.71 /sqm of projected area
Water Wall	=	\$0.00 /sqm of projected area
Trombe Wall	=	\$0.00 /sqm of projected area

Area Weighted Passive Solar Cost = \$63.71 /sqm

Optimum Values are: Buildable Values are:

R wall	=	2.3	----->	2.3
R ceiling	=	2.9	----->	2.9
R perimeter	=	1.2	----->	1.2
R floor	=	ERR	----->	*****
R basement	=	ERR	----->	*****
R glazing	=	0.3	----->	2 panes
ACH	=	0.46	----->	1.00

NOTE: Enter 1.0E+99 for Buildable R values when the optimum is ERR or 0.0

10 - Enter the following building dimensions to calculate the BLC.
 Enter 0.0 for unused components.
 Wall area = (perimeter*ceiling height) - (nonsouth window area + south window area).
 Use Perimeter for slab-on-grade construction.
 Use Floor for vented crawl space.
 Use Basement for heated basement or other fully-bermed wall, including floor losses.
 Combined Floor Area = area of storey 1 + area of storey 2 + ...

Wall Area	=	80.4	sqm
Ceiling (Roof) Area	=	139.4	sqm
Perimeter Length	=	50.3	m
Ground Floor Area	=	0.0	sqm
Basement Wall Length	=	0.0	m
E, N, W Windows	=	6.0	sqm
Ceiling Height	=	2.4	m
Combined Floor Area	=	139.4	sqm
Air Density Ratio	=	1.00	

Component	BLC	
-----	-----	
Wall	3021.0	KJ/DD
Ceiling	4154.7	KJ/DD
Perimeter	2654.9	KJ/DD
Floor	0.0	KJ/DD
Basement	0.0	KJ/DD
Windows	1605.9	KJ/DD
Infiltration	9855.6	KJ/DD

Total BLC =	21292.2	KJ/DD

11 - From the Load Collector Ratio (LCR) table enter those LCR's whose SSF's form the lower and upper bounds of the Selected SSF, i.e. Lower SSF <= Selected SSF <= Upper SSF. Enter 0.0 for the Upper and Lower bounds of unused systems.

	Lower Bound SSF -----		Selected SSF -----		Upper Bound SSF -----
	0.20	<=	0.25	<=	0.30

	Lower Bound LCR -----	***** Selected LCR -----	Upper Bound LCR -----
Sunspace	0	0.0	0
Direct Gain	128	101.5	75
Water Wall	0	0.0	0
Trombe Wall	0	0.0	0

Area Weighted Average LCR = 101.5

Net Passive Solar Projected Area = 10.2 sqm

Sunspace	=	0.0 sqm	(	0.0%)
Direct Gain	=	10.2 sqm	(	100.0%)
Water Wall	=	0.0 sqm	(	0.0%)
Trombe wall	=	0.0 sqm	(	0.0%)

-
- 12 - If a High-Mass Direct-Gain building is selected enter the System Designation, Thermal Storage Capacity, Mass Thickness, Mass-Area-to-Glazing-Area Ratio, No. of Glazings and Night Insul. from Figure 0-2, p. 155, PSDH. Enter the Thermal Storage Capacity and Mass Thickness in the parallel English measure spreadsheet and the conversion to SI units will be performed. The units of the Thermal Storage Capacity are: kJ/°C/sqm. Enter 0.0 for all parameters if unused.

Sys Des'gn	Therm Stor Cap	Mass Thkns (cm)	Mass Area/ Glaz Area Ratio	# of Glazings	Night Insul
B1	918	15.2	3	2	no

 Required Mass Area = 30.7 sqm

-
- 13 - To calculate the Conservation Add-On Cost an assumed reference level (or base case values) for the following parameters must be entered. Enter 1.0E+99 for unused values. Infiltration costs are determined from Table N-2 PSDH.

Component	Base Case	Units	Add-On Cost
Wall	1.9	RSI	\$98.18
Ceiling	2.4	RSI	\$127.63
Perimeter	0.0	RSI	\$281.34
Floor	*****	RSI	\$0.00
Basement	*****	RSI	\$0.00
Windows	1	# panes	\$260.08
Infiltration	1.50	ACH	\$500.00
Total Conservation Add-On Cost =			\$1,267.22
Solar Add-On Cost =			\$551.81
Total Add-On Cost =			\$1,919.04

14 - To calculate the auxiliary heat used enter the # of Degree Days.

DD = 1472

Auxiliary Heat = 23.51 GJ

15 - For comparison purposes the BLC is recalculated using the base-case parameters of Section 12.
Then the auxiliary heat of the base case building is calculated.

Base Case BLC = 32944 KJ/DD

Auxiliary Base Case Heat = 48.49 GJ

16 - The energy saved by the combined conservation and solar strategies is:

Aux Heat (Base Case) = 48.49 GJ/year
Aux Heat (Cons + Solar) = 23.51 GJ/year

24.99 GJ/year

The design costs \$1,919 more than the base case
but saves 24.99 GJ/year in energy
which is an investment of \$76.80 per GJ saved annually

```

*****
*           B A L A N C I N G           *
*                                           *
*   C O N S E R V A T I O N   A N D   S O L A R   *
*****
          *
          ***
          *****
          *****

```

LOTUS 1-2-3 Spreadsheet by Victor Allison - c November 1985

Reference: Passive Solar Design Handbook
Total Environmental Action, Inc. /
Los Alamos Scientific Laboratory /
Los Alamos National Laboratory
New York: Van Nostrand Reinhold Co., 1984.

General Notes:

The user of this spreadsheet must have access to the Passive Solar Design Handbook (or similar) to reference SSF and CF Tables.

SSF = 0.10 corresponds to a threshold passive solar building.
SSF = 0.50 corresponds to a typical passive solar building.
SSF = 0.80 corresponds to a major solar building.

All calculated parameters are surrounded by asterisks like this:

```

*****
Parameter = xxx.yy
*****

```

All parameters not surrounded by asterisks must be entered by the user.

Follow the instructions listed in Blocks 1 - 14.

-
- 1 - Select an initial Solar Savings Fraction (SSF) for the design and enter it under Selected SSF.
Enter 0.1 or 0.5 for the Lower Bound SSF and 0.5 or 0.8 for the Upper Bound SSF.

Lower Bound SSF		Selected SSF		Upper Bound SSF
0.10	<=	0.25	<=	0.50

-
- 2 - Enter the selected System Designation(s) and their Area Weighting(s)
Enter 0.0 for unused systems.
- 3 - From the Conservation Factor (CF) table enter those CF's whose SSF's form the lower and upper bounds of the selected SSF, i.e. lower SSF <= selected SSF <= upper SSF.

System Design	Area Weight CF	Lower SSF CF	***** Selected SSF CF	Upper SSF CF
SS xx	0.00	0.00	0.00	0.00
DG C1	1.00	0.90	1.05	1.30
WW xx	0.00	0.00	0.00	0.00
TW xx	0.00	0.00	0.00	0.00

Area Weighted Average CF = 1.05

-
- 4 - Price the costs for 2 wall systems in \$ per sq. metre using different RSI values (e.g. RSI2 = 2 x RSI1) and enter the values under \$/sqm.
- 5 - Repeat for Floors, Ceiling, heated Basement, Perimeter, Glazing and Infiltration.
 Use Floors for unheated crawlspace.
 Use Perimeter for slab-on-grade.
 Use Basement for heated basement or other fully bermed wall, including floor losses.
 Enter 0.0 under the cost and a dummy value under RSI for unused constructions.

	RSI	\$/sqm
	----	-----
Wall 1	1.9	32.29
Wall 2	6.3	45.75

 Incremental Cost of Wall Insulation = \$3.05 /RSI/sqm

	RSI	\$/sqm
	----	-----
Ceiling 1	5.3	21.53
Ceiling 2	10.6	31.22

 Incremental Cost of Ceiling Insulation = \$1.83 /RSI/sqm

	RSI	\$/m
	-----	-----
Perimeter 1	3.5	6.56
Perimeter 2	7.1	22.97

Incremental Cost of Perimeter Insulation = \$4.66 /RSI/m

	RSI	\$/sqm
	-----	-----
Floor 1	1.8	0.00
Floor 2	2.6	0.00

Incremental Cost of Floor Insulation = \$0.00 /RSI/sqm

	RSI	\$/m
	-----	-----
Perimeter 1	3.5	0.00
Perimeter 2	7.1	0.00

Incremental Cost of Basement Insulation = \$0.00 /RSI/m

	RSI	\$/sqm
	-----	-----
Glazing 1	0.11	53.82
Glazing 2	0.28	96.88

Incremental Cost for One Added Glazing = \$43.06 /sqm
\$246.06 /R/sqm

	ACH	\$/cum
	-----	-----
Infiltr 1	1.00	3.43
Infiltr 2	0.75	3.71

Incremental Cost for Infil. Decrease = \$1.12 /(1/ACH)/cum

-
- 6 - Estimate the cost of the sunspace in \$ per sqm of glazing and enter it.
Enter 0.0 if there is no sunspace.

Feature	\$/sqm
-----	-----
Sunspace	0.00

-
- 7 - Determine a reasonable estimate of the sunspace amenity (appraisal) value and enter it.
This value should be less than that of the Block 6.
Enter 0.0 if there is no sunspace.

	\$/sqm

Sunspace	0.00

-
- 8 - Enter the sunspace's Total Glazed Area and Projected Area.
Enter 1.0E+99 if there is no sunspace.

Total Glazed Area =	*****sqm
Projected Area =	*****sqm

9 - For the other passive features enter the cost of the feature glazing the replaced opaque wall and the moveable insulation (if used). Enter 0.0 for unused features.

Direct Gain Glazing	=	\$96.88 /sqm
Direct Gain Opaque Wall	=	\$32.56 /sqm
Direct Gain Night Insulation	=	\$0.00 /sqm
Water Wall Glazing	=	\$0.00 /sqm
Water Wall Opaque Wall	=	\$0.00 /sqm
Water Wall Night Insulation	=	\$0.00 /sqm
Trombe Wall Glazing	=	\$0.00 /sqm
Trombe Wall Opaque Wall	=	\$0.00 /sqm
Trombe Wall Night Insulation	=	\$0.00 /sqm

Incremental Costs of Passive Solar Features are:

Sunspace	=	\$0.00 /sqm of projected area
Direct Gain	=	\$64.32 /sqm of projected area
Water Wall	=	\$0.00 /sqm of projected area
Trombe Wall	=	\$0.00 /sqm of projected area

Area Weighted Passive Solar Cost = \$64.32 /sqm

Optimum Values are:

Buildable Values are:

R wall	=	2.0	----->	2.0
R ceiling	=	2.6	----->	2.6
R perimeter	=	1.0	----->	1.0
R floor	=	ERR	----->	*****
R basement	=	ERR	----->	*****
R glazing	=	0.2	----->	2 panes
ACH	=	0.51	----->	1.00

NOTE: Enter 1.0E+99 for Buildable R values when the optimum is ERR or 0.0

10 - Enter the following building dimensions to calculate the BLC.
 Enter 0.0 for unused components.
 Wall area = (perimeter*ceiling height) - (nonsouth window area + south window area).
 Use Perimeter for slab-on-grade construction.
 Use Floor for vented crawl space.
 Use Basement for heated basement or other fully-bermed wall, including floor losses.
 Combined Floor Area = area of storey 1 + area of storey 2 + ...

Wall Area	=	80.4	sqm
Ceiling (Roof) Area	=	139.4	sqm
Perimeter Length	=	50.3	m
Ground Floor Area	=	0.0	sqm
Basement Wall Length	=	0.0	m
E, N, W Windows	=	6.0	sqm
Ceiling Height	=	2.4	m
Combined Floor Area	=	139.4	sqm
Air Density Ratio	=	1.00	

Component	BLC	

Wall	3474.1	KJ/DD
Ceiling	4634.1	KJ/DD
Perimeter	2937.2	KJ/DD
Floor	0.0	KJ/DD
Basement	0.0	KJ/DD
Windows	1605.9	KJ/DD
Infiltration	9855.6	KJ/DD

Total BLC =	22507.0	KJ/DD

11 - From the Load Collector Ratio (LCR) table enter those LCR's whose SSF's form the lower and upper bounds of the Selected SSF, i.e. Lower SSF <= Selected SSF <= Upper SSF. Enter 0.0 for the Upper and Lower bounds of unused systems.

	Lower Bound SSF		Selected SSF		Upper Bound SSF
	-----		-----		-----
	0.20	<=	0.25	<=	0.30

	Lower Bound LCR		Selected LCR		Upper Bound LCR
	-----		-----		-----
Sunspace	0		0.0		0
Direct Gain	154		123.0		92
Water Wall	0		0.0		0
Trombe Wall	0		0.0		0

Area Weighted Average LCR = 123.0

Net Passive Solar Projected Area = 8.9 sqm

Sunspace	=	0.0 sqm	(	0.0%)
Direct Gain	=	8.9 sqm	(	100.0%)
Water Wall	=	0.0 sqm	(	0.0%)
Trombe wall	=	0.0 sqm	(	0.0%)

-
- 12 - If a High-Mass Direct-Gain building is selected enter the System Designation, Thermal Storage Capacity, Mass Thickness, Mass-Area-to-Glazing-Area Ratio, No. of Glazings and Night Insul. from Figure O-2, p. 155, PSDH. Enter the Thermal Storage Capacity and Mass Thickness in the parallel English measure spreadsheet and the conversion to SI units will be performed. The units of the Thermal Storage Capacity are: kJ/°C/sqm. Enter 0.0 for all parameters if unused.

Sys Des'gn	Therm Stor Cap	Mass Thkns (cm)	Mass Area/ Glaz Area Ratio	# of Glazings	Night Insul
C1	1224	10.2	6	2	no

 Required Mass Area = 53.5 sqm

-
- 13 - To calculate the Conservation Add-On Cost an assumed reference level (or base case values) for the following parameters must be entered. Enter 1.0E+99 for unused values. Infiltration costs are determined from Table N-2 PSDH.

Component	Base Case	Units	Add-On Cost
Wall	1.9	RSI	\$24.54
Ceiling	2.4	RSI	\$51.05
Perimeter	0.0	RSI	\$234.45
Floor	*****	RSI	\$0.00
Basement	*****	RSI	\$0.00
Windows	1	# panes	\$260.08
Infiltration	1.50	ACH	\$500.00
Total Conservation Add-On Cost =			\$1,070.13
Solar Add-On Cost =			\$574.01
Total Add-On Cost =			\$1,644.14

14 - To calculate the auxiliary heat used enter the # of Degree Days.

DD = 1472

Auxiliary Heat = 24.85 GJ

15 - For comparison purposes the BLC is recalculated using the base-case parameters of Section 12.
Then the auxiliary heat of the base case building is calculated.

Base Case BLC = 32944 KJ/DD

Auxiliary Base Case Heat = 48.49 GJ

16 - The energy saved by the combined conservation and solar strategies is:

Aux Heat (Base Case) = 48.49 GJ/year
Aux Heat (Cons + Solar) = 24.85 GJ/year

23.65 GJ/year

The design costs \$1,644 more than the base case
but saves 23.65 GJ/year in energy
which is an investment of \$69.53 per GJ saved annually

```

*****
*           B A L A N C I N G           *
*                                     *
*   C O N S E R V A T I O N   A N D   S O L A R   *
*****
          *
          ***
          *****
          *****

```

LOTUS 1-2-3 Spreadsheet by Victor Allison - c November 1985

Reference: Passive Solar Design Handbook
 Total Environmental Action, Inc. /
 Los Alamos Scientific Laboratory /
 Los Alamos National Laboratory
 New York: Van Nostrand Reinhold Co., 1984.

General Notes:

The user of this spreadsheet must have access to the Passive Solar Design Handbook (or similar) to reference SSF and CF Tables.

SSF = 0.10 corresponds to a threshold passive solar building.
 SSF = 0.50 corresponds to a typical passive solar building.
 SSF = 0.80 corresponds to a major solar building.

All calculated parameters are surrounded by asterisks like this:

```

*****
Parameter = xxx.yy
*****

```

All parameters not surrounded by asterisks must be entered by the user.

Follow the instructions listed in Blocks 1 - 14.

-
- 1 - Select an initial Solar Savings Fraction (SSF) for the design and enter it under Selected SSF.
Enter 0.1 or 0.5 for the Lower Bound SSF and 0.5 or 0.8 for the Upper Bound SSF.

Lower Bound SSF		Selected SSF		Upper Bound SSF
0.10	<=	0.45	<=	0.50

- 2 - Enter the selected System Designation(s) and their Area Weighting(s)
Enter 0.0 for unused systems.
- 3 - From the Conservation Factor (CF) table enter those CF's whose SSF's form the lower and upper bounds of the selected SSF, i.e. lower SSF <= selected SSF <= upper SSF.

System Design	Area Weight CF	Lower SSF CF	***** Selected SSF CF	Upper SSF CF
SS xx	0.00	0.00	0.00	0.00
DG C1	1.00	0.90	1.25	1.30
WW xx	0.00	0.00	0.00	0.00
TW xx	0.00	0.00	0.00	0.00

Area Weighted Average CF = 1.25

-
- 4 - Price the costs for 2 wall systems in \$ per sq. metre using different RSI values (e.g. $RSI_2 = 2 \times RSI_1$) and enter the values under \$/sqm.
- 5 - Repeat for Floors, Ceiling, heated Basement, Perimeter, Glazing and Infiltration.
 Use Floors for unheated crawlspace.
 Use Perimeter for slab-on-grade.
 Use Basement for heated basement or other fully bermed wall, including floor losses.
 Enter 0.0 under the cost and a dummy value under RSI for unused constructions.

	RSI	\$/sqm
	----	----
Wall 1	1.9	32.29
Wall 2	6.3	45.75

 Incremental Cost of Wall Insulation = \$3.05 /RSI/sqm

	RSI	\$/sqm
	----	----
Ceiling 1	5.3	21.53
Ceiling 2	10.6	31.22

 Incremental Cost of Ceiling Insulation = \$1.83 /RSI/sqm

	RSI	\$/m
Perimeter 1	3.5	6.56
Perimeter 2	7.1	22.97

Incremental Cost of Perimeter Insulation = \$4.66 /RSI/m

	RSI	\$/sqm
Floor 1	1.8	0.00
Floor 2	2.6	0.00

Incremental Cost of Floor Insulation = \$0.00 /RSI/sqm

	RSI	\$/m
Perimeter 1	3.5	0.00
Perimeter 2	7.1	0.00

Incremental Cost of Basement Insulation = \$0.00 /RSI/m

	RSI	\$/sqm
Glazing 1	0.11	53.82
Glazing 2	0.28	96.88

Incremental Cost for One Added Glazing = \$43.06 /sqm
\$246.06 /R/sqm

	ACH	\$/cum
	-----	-----
Infiltr 1	1.00	3.43
Infiltr 2	0.75	3.71

Incremental Cost for Infil. Decrease = \$1.12 /(1/ACH)/cum

-
- 6 - Estimate the cost of the sunspace in \$ per sqm of glazing
and enter it.
Enter 0.0 if there is no sunspace.

Feature	\$/sqm
-----	-----
Sunspace	0.00

-
- 7 - Determine a reasonable estimate of the sunspace
amenity (appraisal) value and enter it.
This value should be less than that of the Block 6.
Enter 0.0 if there is no sunspace.

	\$/sqm

Sunspace	0.00

-
- 8 - Enter the sunspace's Total Glazed Area and Projected Area.
Enter 1.0E+99 if there is no sunspace.

Total Glazed Area =	*****sqm
Projected Area =	*****sqm

9 - For the other passive features enter the cost of the feature glazing the replaced opaque wall and the moveable insulation (if used). Enter 0.0 for unused features.

Direct Gain Glazing	=	\$96.88 /sqm
Direct Gain Opaque Wall	=	\$33.78 /sqm
Direct Gain Night Insulation	=	\$0.00 /sqm
Water Wall Glazing	=	\$0.00 /sqm
Water Wall Opaque Wall	=	\$0.00 /sqm
Water Wall Night Insulation	=	\$0.00 /sqm
Trombe Wall Glazing	=	\$0.00 /sqm
Trombe Wall Opaque Wall	=	\$0.00 /sqm
Trombe Wall Night Insulation	=	\$0.00 /sqm

Incremental Costs of Passive Solar Features are:

Sunspace	=	\$0.00 /sqm of projected area
Direct Gain	=	\$63.10 /sqm of projected area
Water Wall	=	\$0.00 /sqm of projected area
Trombe Wall	=	\$0.00 /sqm of projected area

Area Weighted Passive Solar Cost = \$63.10 /sqm

Optimum Values are:

Buildable Values are:

R wall	=	2.4	----->	2.4
R ceiling	=	3.1	----->	3.1
R perimeter	=	1.3	----->	1.3
R floor	=	ERR	----->	*****
R basement	=	ERR	----->	*****
R glazing	=	0.3	----->	2 panes
ACH	=	0.44	----->	1.00

NOTE: Enter 1.0E+99 for Buildable R values when the optimum is ERR or 0.0

10 - Enter the following building dimensions to calculate the BLC.
 Enter 0.0 for unused components.
 Wall area = (perimeter*ceiling height) - (nonsouth window area + south window area).
 Use Perimeter for slab-on-grade construction.
 Use Floor for vented crawl space.
 Use Basement for heated basement or other fully-bermed wall, including floor losses.
 Combined Floor Area = area of storey 1 + area of storey 2 + ...

Wall Area	=	80.4	sqm
Ceiling (Roof) Area	=	139.4	sqm
Perimeter Length	=	50.3	m
Ground Floor Area	=	0.0	sqm
Basement Wall Length	=	0.0	m
E, N, W Windows	=	6.0	sqm
Ceiling Height	=	2.4	m
Combined Floor Area	=	139.4	sqm
Air Density Ratio	=	1.00	

Component	BLC	

Wall	2895.1	KJ/DD
Ceiling	3886.7	KJ/DD
Perimeter	2533.2	KJ/DD
Floor	0.0	KJ/DD
Basement	0.0	KJ/DD
Windows	1605.9	KJ/DD
Infiltration	9855.6	KJ/DD

Total BLC =	20776.5	KJ/DD

11 - From the Load Collector Ratio (LCR) table enter those LCR's whose SSF's form the lower and upper bounds of the Selected SSF, i.e. Lower SSF <= Selected SSF <= Upper SSF. Enter 0.0 for the Upper and Lower bounds of unused systems.

	Lower Bound SSF -----		Selected SSF -----		Upper Bound SSF -----
	0.40	<=	0.45	<=	0.50

	Lower Bound LCR -----	***** Selected LCR -----	Upper Bound LCR -----
Sunspace	0	0.0	0
Direct Gain	62	52.5	43
Water Wall	0	0.0	0
Trombe Wall	0	0.0	0

Area Weighted Average LCR = 52.5

Net Passive Solar Projected Area = 19.3 sqm

Sunspace	=	0.0 sqm	(	0.0%)
Direct Gain	=	19.3 sqm	(	100.0%)
Water Wall	=	0.0 sqm	(	0.0%)
Trombe wall	=	0.0 sqm	(	0.0%)

-
- 12 - If a High-Mass Direct-Gain building is selected enter the System Designation, Thermal Storage Capacity, Mass Thickness, Mass-Area-to-Glazing-Area Ratio, No. of Glazings and Night Insul. from Figure 0-2, p. 155, PSDH. Enter the Thermal Storage Capacity and Mass Thickness in the parallel English measure spreadsheet and the conversion to SI units will be performed. The units of the Thermal Storage Capacity are: kJ/°C/sqm. Enter 0.0 for all parameters if unused.

Sys Des'gn	***** Therm Stor Cap	***** Mass Thkns (cm)	Mass Area/ Glaz Area Ratio	# of Glazings	Night Insul
-----	-----	-----	-----	-----	-----
C1	1224	10.2	6	2	no
	*****	*****			

 Required Mass Area = 115.8 sqm

-
- 13 - To calculate the Conservation Add-On Cost an assumed reference level (or base case values) for the following parameters must be entered. Enter 1.0E+99 for unused values. Infiltration costs are determined from Table N-2 PSDH.

Component	Base Case	Units	***** Add-On Cost
-----	-----	-----	-----
Wall	1.9	RSI	\$122.72
Ceiling	2.4	RSI	\$178.68
Perimeter	0.0	RSI	\$304.78
Floor	*****	RSI	\$0.00
Basement	*****	RSI	\$0.00
Windows	1	# panes	\$260.08
Infiltration	1.50	ACH	\$500.00
Total Conservation Add-On Cost =			\$1,366.26
Solar Add-On Cost =			\$1,217.88
Total Add-On Cost =			\$2,584.14

14 - To calculate the auxiliary heat used enter the # of Degree Days.

DD = 1472

Auxiliary Heat = 16.82 GJ

15 - For comparison purposes the BLC is recalculated using the base-case parameters of Section 12.
Then the auxiliary heat of the base case building is calculated.

Base Case BLC = 32944 KJ/DD

Auxiliary Base Case Heat = 48.49 GJ

16 - The energy saved by the combined conservation and solar strategies is:

Aux Heat (Base Case) = 48.49 GJ/year
Aux Heat (Cons + Solar) = 16.82 GJ/year

31.67 GJ/year

The design costs \$2,584 more than the base case
but saves 31.67 GJ/year in energy
which is an investment of \$81.59 per GJ saved annually

```

*****
*               B A L A N C I N G               *
*               *                               *
*   C O N S E R V A T I O N   A N D   S O L A R   *
*               *                               *
*****
*
***
*****
*****

```

LOTUS 1-2-3 Spreadsheet by Victor Allison - c November 1985

Reference: Passive Solar Design Handbook
Total Environmental Action, Inc. /
Los Alamos Scientific Laboratory /
Los Alamos National Laboratory
New York: Van Nostrand Reinhold Co., 1984.

General Notes:

The user of this spreadsheet must have access to the Passive Solar Design Handbook (or similar) to reference SSF and CF Tables.

SSF = 0.10 corresponds to a threshold passive solar building.

SSF = 0.50 corresponds to a typical passive solar building.

SSF = 0.80 corresponds to a major solar building.

All calculated parameters are surrounded by asterisks like this:

```

*****
Parameter = xxx.yy
*****

```

All parameters not surrounded by asterisks must be entered by the user.

Follow the instructions listed in Blocks 1 - 14.

-
- 1 - Select an Initial Solar Savings Fraction (SSF) for the design and enter it under Selected SSF.
Enter 0.1 or 0.5 for the Lower Bound SSF and 0.5 or 0.8 for the Upper Bound SSF.

Lower Bound SSF		Selected SSF		Upper Bound SSF
0.10	<=	0.25	<=	0.50

- 2 - Enter the selected System Designation(s) and their Area Weighting(s)
Enter 0.0 for unused systems.
- 3 - From the Conservation Factor (CF) table enter those CF's whose SSF's form the lower and upper bounds of the selected SSF, i.e. lower SSF <= selected SSF <= upper SSF.

System Design	Area Weight CF	Lower SSF CF	Selected SSF CF	Upper SSF CF
SS xx	0.00	0.00	0.00	0.00
DG C1	1.00	0.90	1.05	1.30
WW xx	0.00	0.00	0.00	0.00
TW xx	0.00	0.00	0.00	0.00

Area Weighted Average CF = 1.05

-
- 4 - Price the costs for 2 wall systems in \$ per sq. metre using different RSI values (e.g. $RSI_2 = 2 \times RSI_1$) and enter the values under \$/sqm.
- 5 - Repeat for Floors, Ceiling, heated Basement, Perimeter, Glazing and Infiltration.
 Use Floors for Unheated crawlspace.
 Use Perimeter for slab-on-grade.
 Use Basement for heated basement or other fully bermed wall, including floor losses.
 Enter 0.0 under the cost and a dummy value under RSI for unused constructions.

	RSI	\$/sqm
	-----	-----
Wall 1	1.9	32.29
Wall 2	6.3	45.75

 Incremental Cost of Wall Insulation = \$3.05 /RSI/sqm

	RSI	\$/sqm
	-----	-----
Ceiling 1	5.3	21.53
Ceiling 2	10.6	31.22

 Incremental Cost of Ceiling Insulation = \$1.83 /RSI/sqm

	RSI	\$/m
	-----	-----
Perimeter 1	3.5	6.56
Perimeter 2	7.1	22.97

 Incremental Cost of Perimeter Insulation = \$4.66 /RSI/m

	PSI	\$/sqm
	-----	-----
Floor 1	1.8	0.00
Floor 2	2.6	0.00

Incremental Cost of Floor Insulation = \$0.00 /RSI/sqm

	RSI	\$/m
	-----	-----
Perimeter 1	3.5	0.00
Perimeter 2	7.1	0.00

Incremental Cost of Basement Insulation = \$0.00 /RSI/m

	RSI	\$/sqm
	-----	-----
Glazing 1	0.11	53.82
Glazing 2	0.28	96.88

Incremental Cost for One Added Glazing = \$43.06 /sqm
\$246.06 /R/sqm

	ACH	\$/cum
	-----	-----
Infiltr 1	1.00	3.43
Infiltr 2	0.75	3.71

Incremental Cost for Infil. Decrease = \$1.17 /(1/ACH)/cum

-
- 6 - Estimate the cost of the sunspace in \$ per sqm of glazing and enter it.
Enter 0.0 if there is no sunspace.

Feature	\$/sqm
Sunspace	0.00

-
- 7 - Determine a reasonable estimate of the sunspace amenity (appraisal) value and enter it.
This value should be less than that of the Block 6.
Enter 0.0 if there is no sunspace.

	\$/sqm
Sunspace	0.00

-
- 8 - Enter the sunspace's Total Glazed Area and Projected Area.
Enter 1.0E+99 if there is no sunspace.

Total Glazed Area =	*****sqm
Projected Area =	*****sqm

9 - For the other passive features enter the cost of the feature glazing the replaced opaque wall and the moveable insulation (if used). Enter 0.0 for unused features.

Direct Gain Glazing	=	\$96.88 /sqm
Direct Gain Opaque Wall	=	\$56.98 /sqm
Direct Gain Night Insulation	=	\$0.00 /sqm
Water Wall Glazing	=	\$0.00 /sqm
Water Wall Opaque Wall	=	\$0.00 /sqm
Water Wall Night Insulation	=	\$0.00 /sqm
Trombe Wall Glazing	=	\$0.00 /sqm
Trombe Wall Opaque Wall	=	\$0.00 /sqm
Trombe Wall Night Insulation	=	\$0.00 /sqm

Incremental Costs of Passive Solar Features are:

Sunspace	=	\$0.00 /sqm of projected area
Direct Gain	=	\$39.90 /sqm of projected area
Water Wall	=	\$0.00 /sqm of projected area
Trombe Wall	=	\$0.00 /sqm of projected area

Area Weighted Passive Solar Cost = \$39.90 /sqm

Optimum Values are:

Buildable Values are:

R wall	=	1.6	----->	3.5
R ceiling	=	2.1	----->	7.0
R perimeter	=	0.6	----->	1.0
R floor	=	ERR	----->	*****
R basement	=	FPR	----->	*****
R glazing	=	0.2	----->	2 panes
ACH	=	0.65	----->	0.50

NOTE: Enter 1.0E+99 for Buildable R values when the optimum is ERR or 0.2

10 - Enter the following building dimensions to calculate the BLC.
 Enter 0.0 for unused components.
 Wall area = (perimeter*ceiling height) - (nonsouth window area + south window area).
 Use Perimeter for slab-on-grade construction.
 Use Floor for vented crawl space.
 Use Basement for heated basement or other fully-bermed wall, including floor losses.
 Combined Floor Area = area of storey 1 + area of storey 2 + ...

Wall Area	=	80.4	sqm
Ceiling (Roof) Area	=	139.4	sqm
Perimeter Length	=	50.3	m
Ground Floor Area	=	0.0	sqm
Basement Wall Length	=	0.0	m
E, N, W Windows	=	6.0	sqm
Ceiling Height	=	2.4	m
Combined Floor Area	=	139.4	sqm
Air Density Ratio	=	1.00	

Component	RLC	
-----	-----	
Wall	1095.2	KJ/DD
Ceiling	1721.3	KJ/DD
Perimeter	2937.2	KJ/DD
Floor	0.0	KJ/DD
Basement	0.0	KJ/DD
Windows	1605.9	KJ/DD
Infiltration	4927.8	KJ/DD
-----	-----	
Total BLC =	13177.4	KJ/DD

- 11 - From the Load Collector Ratio (LCR) table enter those LCR's whose SSF's form the lower and upper bounds of the Selected SSF, i.e. Lower SSF <= Selected SSF <= Upper SSF. Enter 0.0 for the Upper and Lower bounds of unused systems.

	Lower Bound SSF		Selected SSF		Upper Bound SSF
	0.20	<=	0.25	<=	0.30
	-----		-----		-----
	Lower Bound LCR		Selected LCR		Upper Bound LCR
	-----		-----		-----
Sunspace	0		0.0		0
Direct Gain	154		123.0		92
Water Wall	0		0.0		0
Trombe Wall	0		0.0		0

Area Weighted Average LCR = 123.0

Net Passive Solar Projected Area = 5.2 sqm

Sunspace = 0.0 sqm (0.0%)
Direct Gain = 5.2 sqm (100.0%)
Water Wall = 0.0 sqm (0.0%)
Trombe Wall = 0.0 sqm (0.0%)

-
- 12 - If a High-Mass Direct-Gain building is selected enter the System Designation, Thermal Storage Capacity, Mass Thickness, Mass-Area-to-Glazing-Area Ratio, No. of Glazings and Night Insul. from Figure D-2, p. 155, PSDH. Enter the Thermal Storage Capacity and Mass Thickness in the parallel English measure spreadsheet and the conversion to SI units will be performed. The units of the Thermal Storage Capacity are: kJ/°C/sqm. Enter 0.0 for all parameters if unused.

Sys Des'gn	Therm Stor Cap	Mass Thkns (cm)	Mass Area/ Glaz Area Ratio	# of Glazings	Night Insul
C1	1224	10.2	6	2	no

 Required Mass Area = 31.3 sqm

-
- 13 - To calculate the Conservation Add-On Cost an assumed reference level (or base case values) for the following parameters must be entered. Enter 1.0E+99 for unused values. Infiltration costs are determined from Table N-2 PSDH.

Component	Base Case	Units	Add-On Cost
Wall	1.9	RSI	\$392.70
Ceiling	2.4	RSI	\$1,174.18
Perimeter	0.0	RSI	\$234.45
Floor	*****	RSI	\$0.00
Basement	*****	RSI	\$0.00
Windows	1	# panes	\$260.08
Infiltration	1.50	ACH	\$500.00
Total Conservation Add-On Cost =			\$2,561.41
Solar Add-On Cost =			\$208.48
Total Add-On Cost =			\$2,769.89

14 - To calculate the auxiliary heat used enter the # of Degree Days.

DD = 1472

Auxiliary Heat = 14.55 GJ

15 - For comparison purposes the BLC is recalculated using the base-case parameters of Section 12.
Then the auxiliary heat of the base case building is calculated.

Base Case BLC = 32944 MJ/DD

Auxiliary Base Case Heat = 43.49 GJ

16 - The energy saved by the combined conservation and solar strategies is:

Aux Heat (Base Case) = 43.49 GJ/year
Aux Heat (Cons + Solar) = 14.55 GJ/year

33.95 GJ/year

The design costs \$2,770 more than the base case
but saves 33.95 GJ/year in energy
which is an investment of \$81.40 per GJ saved annually

18. APPENDIX 9 - SUMMARY OF MONTHLY EVALUATIONS

January

- * Insulate.
- * Tight construction.
- * Promote solar gain on south, west and roof.
- * Protect from prevailing northwest - southeast winds.

February

- * Insulate.
- * Tight construction.
- * Promote solar gain on east, south, west and roof.
- * Protect from prevailing northwest - southeast winds.
- * Low mass eastern construction.

March

- * Insulate.
- * Tight construction.
- * Promote solar gain on east, south, west and roof.
- * Restrict solar gain on south when the sun's altitude is greater than 55 degrees.
- * Prevailing northwest - southeast winds.
- * Less than 5% ventilation or evaporative cooling.
- * Low mass eastern construction.

April

- * Insulate.
- * Tight construction.
- * Promote solar gain on east and intermittently on south and west.
- * Adjustable shading devices on west.
- * Thermal mass on west.
- * Prevailing northwest - southeast winds.
- * 5% ventilation and evaporative cooling.
- * Low mass eastern construction.

May

- * Insulate.
- * Tight construction.
- * Promote solar gain on east.
- * Low mass eastern construction.
- * Eliminate solar gain on south and west with exterior shading devices.
- * Roof venting.
- * Light colored roof surface.
- * Thermal mass on west.
- * Allow cross ventilation from prevailing northwest wind.
- * Specify evaporative cooling system.
- * Interior mass for nighttime ventilation-cooling.

June

- * Insulate.
- * Tight construction.
- * Promote some solar gain on east.
- * Low mass eastern construction.
- * Eliminate solar gain on south and west with exterior shading devices.
- * Roof venting.
- * Light colored roof surface.
- * Thermal mass on west.
- * Allow cross ventilation from prevailing northwest wind.
- * Specify evaporative cooling system.
- * Interior mass for nighttime ventilation-cooling.

July

- * Insulate.
- * Tight construction.
- * Promote some solar gain on east.
- * Low mass eastern construction.
- * Eliminate solar gain on south and west with exterior shading devices.
- * Roof venting.
- * Light colored roof surface.
- * Thermal mass on west.
- * Allow cross ventilation from prevailing northwest wind.
- * Specify evaporative cooling system.
- * Interior thermal mass to temper daytime temperature fluctuations.

August

- * Insulate.
- * Tight construction.
- * Promote some solar gain on east.
- * Low mass eastern construction.
- * Eliminate solar gain of south and west with exterior shading devices.
- * Roof venting.
- * Light colored roof surface.
- * Thermal mass on west.
- * Allow cross ventilation from prevailing northwest wind.
- * Specify evaporative cooling system.
- * 4% compressor cooling required.
- * Interior thermal mass to temper daytime temperature fluctuations.

September

- * Insulate.
- * Tight construction.
- * Promote solar gain on east.
- * Low mass eastern construction.
- * Eliminate solar gain on south and west with exterior shading devices.
- * Roof venting.
- * Light colored roof surface.
- * Thermal mass on west.
- * Allow cross ventilation from prevailing northwest wind.
- * Specify evaporative cooling system.
- * Interior mass for nighttime ventilation-cooling.

October

- * Insulate.
- * Tight construction.
- * Promote solar gain on east.
- * Low mass eastern construction.
- * Eliminate solar gain on south and west with exterior shading devices.
- * Roof venting.
- * Light colored roof surface.
- * Thermal mass on west.
- * Allow cross ventilation from prevailing northwest wind.
- * Specify evaporative cooling system.
- * Interior mass for nighttime ventilation-cooling.

November

- * Insulate.
- * Tight construction.
- * Promote solar gain on east, south, west and roof.
- * Promote solar gain when sun's altitude is less than 38 degrees.

December

- * Insulate.
- * Tight construction.
- * Promote solar gain on east, south, west and roof.
- * Protect from prevailing northwest - southeast winds.

19. APPENDIX 10 - CLIMATE DATABASES FOR BUILDING DESIGN

This appendix begins with a discussion of the method employed by the National Climatic Center to generate a TMY. It continues with an evaluation of the appropriateness of "typical" data as input to the building bioclimatic analysis model in light of other possible databases such as "extreme" data.

The generation of a TMY began with the selection of four meteorological measures: dry bulb temperature, dew point temperature, wind velocity and global solar radiation on a horizontal surface. From these four measures, a total of thirteen daily indices were generated: daily total global solar radiation and daily maximum, minimum, mean and range for each of dry bulb temperature, dew point temperature and wind velocity. For each month of each year of the twenty year dataset there is a distribution associated with each of the daily indices - for example, the distribution of the daily means of wind velocities for February 1965. Additionally, each month has a long term distribution corresponding to each of the daily indices - for example, the distribution of daily means of wind velocities for each day in February over the entire twenty year dataset. Ideally, a typical meteorological month would be one month of the twenty year dataset whose individual distributions for all thirteen daily indices were "close" to their thirteen corresponding long term indices. Typically, it is impossible to find such a combination.

Depending on the application of the TMY, the different indices

will take on differing levels of importance. Therefore, to generate a TMY one must assign a "weighting" to each of the indices and be content with matching the "important" indices. The weighting used for the TMY leans heavily towards insolation with dry bulb and dew point temperatures and wind velocity being of approximately equal, but lesser, importance. It was determined that the three range statistics and the minimum wind velocity were of little or no value in the selection process and so were omitted.

The selection of the typical meteorological month was divided into two steps. First, five so called "candidate" months were selected from the twenty year dataset and then a final selection was made from the five candidate months. The candidate months were selected through a statistical analysis comparing each of the monthly indices with the corresponding indices for the twenty year dataset. The final selection of the typical month from the candidate months involved the examination of various statistical measures and persistence structure associated with the daily mean dry bulb temperature and daily total global solar radiation. The persistence is a statistical measure of the frequency and run length of the temperature (or insolation) above and below the long term percentiles of these parameters. Persistence was considered to be important as it is possible that the statistical measures of a given month's indices could be close to that of the twenty year composite and yet there still could be atypical long runs of cloudy or warm or cool days. This type of occurrence

would be of particular importance when considering solar energy systems.

As the TMY consists of the concatenated typical months any discontinuities between the end of one month and the beginning of the next were smoothed out through the use of a cubic spline on the pressure, temperature and wind velocity measurements.

There has been no extensive validation performed to determine just how "typical" any generated TMY database is. Research performed at the University of Wisconsin has assessed the TMY for Madison, Wisconsin and determined that the TMY measures are within one standard deviation of the database mean - a result which is supportive of the TMY[1].

The use of TMY data for the model was selected as, unlike averaged data, the TMY still contains runs of extreme weather that would be smoothed out in an averaged database. For example, a week long period of cloudy weather and its associated diminished insolation levels would not appear in an averaged database. If averaged insolation levels were used, the subsequently derived preliminary design guidelines would only reflect an "average energy performance" in the building. It is likely that this would give the erroneous impression that comfort could be maintained either passively or with less reliance on mechanical heating or cooling than would, in fact, be the case.

Conversely, one could argue that the database should provide the model with worst case (extreme) data. However this raises several questions on the exact nature of the definition of worst case data. First consider data for the month of January. Would the database contain temperature measurements for the coldest or hottest hour for each day? Or would it contain data describing the greatest spreads between daytime and nighttime values? As it is extremely unlikely that any January would have each and every hour with the minimum recorded temperature, how would one decide for how many hours in a row the worst case conditions would exist and on which days would they exist? Or would one consider maximum or minimum vapor pressure values as defining a worst case condition? Similar arguments exist for defining worst case summer conditions. How would one approach the transition months when both heating and cooling loads come into play? And finally, if sound answers could be found for the above questions would one be able to employ the same decision strategy for differing geographic locations?

As the generation of a TMY is a non-trivial problem, it is unlikely that the typical user of the building bioclimatic analysis model would have the technical and mathematical expertise to generate an alternative database. Additionally, the generation of a user defined database would require access to the 20 year dataset as well as main frame computing facilities.

The ultimate validation of the use of TMY data versus an

alternative database would be, firstly, a comparison between the generated design strategies and then, if they proved to be significantly different, a real world evaluation of the performance of the alternative buildings.

It would be foolhardy for any architect to design a building using bioclimatic methods and a TMY database and not make allowances for atypical climatic conditions. To this end the architect should ensure that backup mechanical heating and/or cooling meet the minimum recommended standards for mechanical system design. Typically, this requires that mechanical systems be designed to ensure comfort in a building for all but the extreme two percent of the yearly temperature range.

[1]

I. J. Hall, R. R. Prairie, H. E. Anderson and E. C. Boes, Generation of Typical Meteorological Years for 26 SOLMET Stations, (Albuquerque, NM: Sandia Laboratories), p. 9.

20. APPENDIX 11 - COMFORT ZONE MODIFICATIONS

As was stated in section 6.1.3 the model can be altered to accommodate differing human comfort zones through a modification of files *BCCDATA* and *BCPDATA*. Changing the parameters in *BCCDATA* would alter the appearance of the chart produced by PSYCHART. Modifications to *BCPDATA* would directly affect file *DATANEED* as well as the output of programmes SPSSXNED, OCCURPLT, SCCPLOT, SCCBAR and SOLPATH as they all feed off of *DATANEED*. See Figure 3.1.

In addition to temperature and relative humidity (or vapor pressure) comfort is a function of several other parameters. These include clothing, activity levels, radiant temperatures of adjacent surfaces, air movement within the occupied space, variations in temperature over time, vertical temperature differences within the space, radiant asymmetry of adjacent hot and cold surfaces and floor temperatures. These factors are discussed in detail in both the ASHRAE Handbook - 1985 Fundamentals and ANSI/ASHRAE STD 55-1981. Included in these sources are various graphs and charts that indicate how the comfort zone is effected by changing parameters. The comfort zone in the building bioclimatic analysis model could be altered by first selecting the parameter of interest, such as changing the clo level, and then applying the appropriate chart to account for the change. A study of Milne and Givoni (1979) would also be required to ensure that the boundaries of the other zones still met the physical requirements of each strategy. For example, reducing the upper temperature of the comfort zone would

necessitate an alteration in the sloping boundary of the promote evaporative cooling zone in order to ensure that it met the upper corner of the comfort zone along a line of constant enthalpy.

See Figure 2.4.

21. APPENDIX 12 - THE SOLAR SAVINGS FRACTION

The analytical procedure that the spreadsheet calculations are based upon rely solely on considerations of the heating season. It was recommended in section 2.4 that when designing for locations for which cooling loads must be satisfied the architect lean more towards conservation strategies by selecting a "lower" solar savings fraction. This shift in emphasis was deemed appropriate as extensive solar features are likely to result in overheating problems during the summer season. Unfortunately, the spreadsheet does not permit the architect to assess the overheating potential of a selected solar savings fraction. The analysis presented does not permit the architect to determine a solar savings fraction "break-point" or value beyond which the use of passive systems becomes a liability during the summer season.

An analysis to determine an optimum solar savings fraction would require specific design details such as the sizes of both the glazed areas and thermal mass as well as the anticipated insolation levels. Although estimates of these figures are available from both the spreadsheet and building bioclimatic analysis model the calculations required are more in the realm of an engineer's expertise and are not elaborated upon in this document.