CONSERVATORIES AND DOMESTIC HEATING

by

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ABSTRACT

Passive solar gains to buildings in North European Climates can be significant and an investigation is made into the effect of orientation upon solar gains based upon known weather data.

The conservatory is a particularly useful collector because of its inclusion to existing houses and its desirability to the householder for reasons other than solar collection. A conservatory was adapted and monitored. A computer model was written. The behaviour of the conservatory was examined for various criteria.

The possibility of inclusion of a conservatory into houses in the existing housing stock was examined. The effect of occupancy on heating demand and solar delivery was reviewed and the likely overall energy saving was examined.

A new house system was developed including the use of a first floor concrete slab and a gas warm air heating unit. A concrete floor slab was cast to examine its storage potential.

A preliminary design for the heating system of the new houses was undertaken.

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NOTATION

A	: Area	m^2
Ag	: Area of glass	m^2
C	: Empirical discharge coefficient	
F	: Configuration factor	
GR	: Ground reflectance component	
Gr	: Grashof number	
I_D	: Direct irradiance	W/m^2
I_{Dbeam}	: Direct irradiance on the beam	W/m^2
I_{Dd}	: Design direct irradiance	W/m^2
I_{DHd}	: Design direct irradiance on a horizontal surface	W/m^2
I_{Dv}	: Direct irradiance on a vertical surface	W/m^2
I_d	: Diffuse (sky) irradiance	W/m^2
I_{dH}	: Diffuse (sky) irradiance on a horizontal surface	W/m^2
I_{dHd}	: Design diffuse (sky) irradiance on a horizontal surface	W/m^2
I_{TH}	: Total (global) irradiance on a horizontal surface	W/m^2
I_{THd}	: Design total irradiance on a horizontal surface	W/m^2
I_{TV}	: Total (global) irradiance on a vertical surface	W/m^2
I_{TVd}	: Design total irradiance on a vertical surface	W/m^2
L	: Length	m
Nu	: Nusselt number	
P	: Absolute pressure	Pa
Pr	: Prandtl number	
Q	: Heat flow	W/m^2
Q_c	: Heat flow by convection	W/m^2
Q_G	: Gross heat flow	W/m^2

Q_N	: Net heat flow	W/m^2
Q_V	: Volume flow rate	m^3/s
Q_{hriz}	: Total solar irradiance on the horizontal	W/m^2
Q_{vert}	: Total solar irradiance on the vertical	W/m^2
R	: Thermal resistance	m^2K/W
R_{si}	: Internal surface resistance	m^2K/w
R_{so}	: External surface resistance	m^2K/W
T	: Temperature	K
T'	: Temperature at preceeding time interval	K
TAI	: Inside air temperature	K
TAO	: Outside air temperature	K
T_{bwall}	: Temperature of logger room back wall	K
T_{cons}	: Conservatory air temperature	K
TC	: Conservatory air temperature	K
TD	: Time of day	h
TEI	: Environmental temperature	K
TEO	: Sol-air temperature	K
T_{floor}	: Temperature of conservatory floor	K
T_{log}	: Air temperature of logger room	K
U	: U-Value	W/m^2K
Ug	: U-Value of glass	W/m^2K
Uw	: U-Value of wall	W/m^2K
Z	: Discharge correction factor	
a	: Thermal absoptivity	
c	: Thermal heat capacity	J/kgK

d	: Distance / diameter	m
h	: Height	m
h	: Heat transfer coeficient for horizontal surface	W/m^2K
h	: Heat transfer coeficient for vertical surface	W/m^2K
h	: Convective heat transfer coefficient	W/m^2k
h	: Radiative heat transfer coeficient	W/m^2K
k	: Thermal conductivity	W/m^2K
n	: Day´s number in year	
q_i	: Heat Input	W
q_v	: Heat Loss due to Ventilation	W
q_w	: Heat Loss from Wall	W
s	: Solar admittance factor	
t	: Time	s
α	: Altitude of sun	
δ	: Declination of the Earth	
ϵ	: Solar Azimuth / Emmisivity	
E	: Expansibilty factor	
γ	: Angle between Surface and Solar Azimuth	
ρ	: Density	kg/m
ϕ	: Latitude	
μ	: Dynamic viscosity	kg/m
ω	: Hour Angle	

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CHAPTER 1 INTRODUCTION

Much emphasis in the design of new houses and the rehabilitation of older houses in recent years has been placed upon the reduction of heating costs. This is not only because of the increasing costs of fuel but also because of the growing realisation that our present reserves of fuel, particularly fossil fuel, are dwindling.

1.1 Insulation and Energy Saving Measures

In the past decade there has been a large increase in energy saving devices in both existing and new houses. These include draught exclusion, loft insulation, double glazing and cavity wall insulation.

Recent Building Regulations have required a great increase in insulation . New homes now come complete with good insulation and often highly efficient space heating systems.

We have also seen the growth of active solar systems in which a liquid is heated in a solar panel usually on the roof. Although much success has been had with these systems in Southern Europe and America, their suitability for space heating in North Europe is suspect due to the climate.

1.2 Passive Solar Energy

Passive solar collection is far simpler than active. At its crudest, it involves the orientation of the building, the building's shape and the correct positioning of the windows. These will be investigated. None of them need add to the cost of construction, however they may only be implemented in new buildings. This would limit the potential of passive solar measures since we are likely to have to rely upon our existing buildings, many of which are pre-war and some considerably older, for many decades to come. It would therefore be wiser to consider a system which satisfied the needs of existing buildings, yet was able to be incorporated into new ones.

There are many kinds of passive solar systems, of which some can be used in both old and new buildings. They work with varying degrees of success in the British climate. Some of these include a conservatory or 'sunspace' which has the advantage of being a commonly available structure that is intrinsically valued and is therefore more likely to be readily acceptable to builders and home owners alike if it can be shown to have thermal advantages.

1.3 Insulation and Passive Solar Energy

A poorly insulated house has a high energy demand due to high fabric heat loss. Passive solar energy may make a great contribution under these circumstances. However, if the house is well insulated, often at fairly low cost, or built to current building regulations, then the fabric loss is considerably reduced. Given lower fuel bills from lower fabric loss, the potential total saving from passive solar energy may be reduced. Generally the payback period for any system concerned with reducing fuel costs due to fabric losses is long. It is usually more financially viable to improve insulation rather than to incorporate a passive solar feature.

Modern houses have a lower level of draughts, little heat being lost by escaping warm air and incoming cold air. There is a limit to how much ventilation may be reduced, since some fresh air must enter the house to maintain comfort conditions. The level of ventilation is difficult to recommend since it is dependent upon the rate of pollution within the building, which is in turn dependent upon the number of occupants, the amount of cooking, combustion in open fires and cigarette smoking.

Insufficient ventilation results in unpleasant odour from the occupants and cooking, a high humidity level as well as a lack of oxygen which can produce drowsiness or illness.

Recommended guidelines (I.H.V.E.,1971) suggest a minimum level of 21 m^3/h of fresh air per person. This equates to the rule of thumb of one complete air change per hour in normal housing. Highly dense areas and places with large amounts of cooking etc. need higher levels, usually provided by mechanical means. Therefore no matter how well insulated a house is, there is still a need to bring external air into the house. If any passive solar system can warm up this external air there is no loss of solar efficiency with increased ventilation. The house would be well insulated and thus have a low fabric loss. Fuel would be saved by reducing the amount necessary to provide for the fabric loss, perhaps reducing the heating season at the beginning and end, but more particularly fuel would be saved on the increased temperature of the incoming air for ventilation.

1.4 The Conservatory

Conservatories of one form or another have been in use in the U.K. for two centuries or more. They have been used as lean-to glass houses for the propagation of plants etc. and are a pleasant addition to the ordinary house creating, on occasions, an indoor garden.

The benefits of an attached conservatory are summarised by Turrent, Doggart and Ferraro (1980):

1) It helps to reduce heat losses from the main part of the building by increasing thermal resistance.

2) It acts as a passive solar collector, delivering useful quantities of heat into the house.

3) It provides an extension to the living space, which is usable for a large part of the year.

A conservatory could be considered as analogous to the Trombe Wall on the side of a house with a thermal storage wall between it and the house. Assuming that the conservatory is not to be used once the sun has set, the air temperature within the conservatory does not require very good thermal control. Occupants may, however, heat their conservatory such that they may continue to use it in the evening or early morning. This obviously detracts from its use as a collector and may result in more - not less- fuel consumption.

Problems arise however with the use of the conservatory as a solar collector. Overshadowing and reduction of light in the house may occur when a conservatory is added, hence the desirability of it providing an acceptable living space.

Cost may prevent the use of double glazing, although this is becoming more popular with commercial ventures. Construction is rarely airtight and thus one can expect a flow of warm air to the outside. If the conservatory is linked to the house, the interchange of air from it to the house is relatively easy although the conservatory should help to reduce unwanted draughts. To control high summer air temperatures, adequate top and bottom openable glazing is required. Sun shading may also be needed and this can be achieved in various ways including the use of plants and deciduous trees.

The conservatory has a poor resistance to conduction losses. Its thermal benefits are likely to be strongly dependent upon the physical properties of the wall between the conservatory and the living space and by the efficiency by which heat may be transferred from the conservatory to the dwelling. It may be possible to have additional movable insulation between the house and the conservatory to reduce losses at night.

1.5 The Performance of the Conservatory

The performance of a conservatory is obviously dependent upon the weather. Table 1.1 shows what this is likely to be in the south of the United Kingdom. The average temperature (C.I.B.S.E.,1982) is a 24 hour average over each month at Kew for the ten years 1959-68. The monthly global radiation (Meteorological Office,1981) is for a south facing vertical surface at Easthampstead, Berkshire and is the total radiation for the month averaged over the nine years 1967-75. The number of hours sunshine (Meteorological Office,1981) is a ten year monthly average.

At a simple level, it is possible to consider the reduction of heat loss from a wall due to an attached conservatory and the contribution of the conservatory to the prewarming of any fresh air necessary for ventilation. There will be additional gains such as the likely buffer gain, thanks to there being an additional zone of warm air attached to the house, and fabric gains from the natural storage of the conservatory. The total contribution of the conservatory will be considered in detail below.

The sol-air temperature is defined as (Markus & Morris, 1980) the increased external temperature which could produce the sam internal temperature rise as would be obtained with the solar radiation acting in conjuntion with the actual external air temperature. The equation for the sol air-temperature is:

$$TEO = TAO + as\ T_{TV}R_{so} \qquad (1.1)$$

The long wave radiation term has been ommited for simplicity since high accuracy is not required at this stage. a is the solar absorptance taken as 0.5 and R_{so} as 0.06 m^2K/W (CIBSE, 1971). s, the amount of radiation transmitted, was taken as 1.0 when there was no glass and 0.76 when there was. R_{so} for the wall and conservatory was 0.30 m^2K/W. I_{TV} is the monthly average global radiation on the vertical surface in W/m^2 calculated from the data in Table 1.1 for Meteorological data for the sum of the whole month.

The average monthly sol-air temperature was calculated using equation (1.1) from the data in Table 1.1 for an ordinary south facing cavity brick wall and the same brick wall covered by a conservatory. The resulting sol-air temperatures are shown in Table 1.2.

A simple steady state calculation was made for the heat loss through the wall in the form of:

$$q_w = \sum AU\ (TEO - TEI) \qquad (1.2)$$

For the purpose of simplicity TEI was taken to be TAI. The conservatory was assumed to be 3m wide by 2.8m high covering a cavity wall. No window area in the wall was considered. The results were calculated on a monthly basis with an internal air temperature of 20^{o}C.

The results are shown in Figure (1.1a) for a normal solid wall of thickness 200mm and area 8.4 m^2, and the same wall with an attached conservatory. The shaded area is the net saving. Of note is that in September, April and May there is a net gain through the wall from the conservatory. There is very little variation in saving from month to month, the lowest being 190 MJ/month in December, the highest 250 MJ/month in April.

1.5.1 Ventilation Gain

The heat loss due to bringing in fresh air for the purpose of ventilation may be expressed as:

$$q_V = \rho \, cv \, (TAI - TAO) \qquad (1.3)$$

If all the air could be supplied from the conservatory, the heat loss is:

$$q_V' = \rho \, cv \, (TAI - TC) \qquad (1.4)$$

The air temperature of the conservatory TC, may be crudely estimated from an admittance calculation:

$$sI_{TV}Ag = (TC - TAO)(AgUg + \rho cv) + (TC - TAI)\ Uw\ Aw \qquad (1.5)$$

Where Uw is the U value of the wall, taken as 1.5 W/m^2K and Aw as the area of the wall at 8.4 m^2. For simplicity, Ag is taken to be the same as Aw, 8.4 m^2, i.e. considering the conservatory to be a shallow collector. The other dimensions are as above. The internal temperature of the house was taken to be 20 ^oC. Ug was 5.7 W/m^2K.

If the ventilation rate is considered to be one air change an hour in a house of 180 m^3, an average monthly value of TC may be calculated. The results for this are shown in Table 1.3. Using equations (1.3) and (1.4) the overall ventilation heat losses may be estimated. The results are shown in Fig(1.1b), once again the shaded area is the net saving.

There is a variation in the net saving with the peak of 1000 - 1200 MJ/month being achieved in the middle of the heating season.

In practice, the figures are likely to be lower since we are dealing with simplified averages and assuming 24 hour occupancy and unvarying demand. But they do indicate the potential benefit of a conservatory. A system could be developed which would ensure that most of the air necessary for ventilation could be taken from the conservatory and could easily be warmed to comfort conditions without a complicated heating system.

1.6 Occupancy and Fuel Usage

Important in any passive solar system is the likely occupancy of the dwelling. Occupancy patterns fall roughly into two groups: domestic and non domestic. Non domestic includes offices, schools, public buildings and some factories which are generally used during the day and little or not at all in the evening. These are outside of the scope of this work.

Domestic occupancy often, but not always, means that the house is empty during the day. This poses problems of storage of heat and possibly orientation of the conservatory to maximise the output at time of need. The time that heat is needed will vary from household to household depending upon many variables such as household size, work patterns etc. An attempt will be made to quantify the different heating regimes that exist.

1.7 Storage

To benefit from solar energy it is generally necessary to store the heat so that it may be available when it is required. This poses many problems, not least of which is the difficulty of storing low grade heat and the general inefficiency of most heat stores.

Some natural storage is inherent in any form of construction. The conservatory itself will have some natural storage, particularly in the floor, but will tend to lose heat easily and hence much of this stored heat may be lost to the outside. Removable insulation may be provided to reduce this heat loss at times of no sunshine, as suggested by Sodha, Nayak, Bansal and Goyal (1982).

A 'thermal wall' can be placed between the conservatory and the house. In a simulated model (Nayak, Bonsal & Sodha, 1983) a 0.22m thick concrete partition was found to give an almost constant heat flux into the living room. This however necessitates a different and more expensive external construction than is traditional. Additionally, many modern houses are of lighter construction, reducing the amount of natural storage the house will possess, and an additional heat store will be required if a conservatory's output is to be maximised. This could take many forms and be in any part of the house. Typical solutions have included large outer walls, thermal chimneys and heat storing basements (Lebens, 1980).

The most significant problem with any store is its inefficiency. It loses heat continually, even when it is not wanted. All of the store's surfaces will lose heat and this may result in the loss of heat to the outside or to the ground. Insulation may partially overcome this. If by contrast all of the surfaces of the store are in contact with the inside of the dwelling, any losses will be to the house and although they may be at undesirable times they are likely to be of some benefit since they will warm the house and thus make the heating 'start up' easier.

A good position in a two-storey house for such a store is the first floor. Apart from the edges of the floor, which are minimal, all surfaces are in contact with the inside. Traditionally, the first floor is of timber, but if it could be of concrete, it could then be used as a heat store. Precast concrete floors are now available in a range of sizes from many manufacturers and the majority of them have a hollow section, usually consisting of 50mm diameter holes running the length of the slab. These could be used to pass warm air through from the conservatory and thus charge the slab with heat.

1.8 Prewarmed Air

As mentioned above, there is much to be gained by using prewarmed air from the conservatory for ventilation since it has a thermal contribution to make, no matter how low its temperature is, provided the conservatory air is warmer than the outside air. This will be investigated below.

There are two problems with the use of prewarmed air for ventilation:

1) Storage.

2) Temperature.

The concrete store as described in section 1.6 can be charged by passing warm air, when available from the conservatory, through it. When ventilating air is required this may be brought through the conservatory, via the concrete floor where it may be warmed by the slab. In this way the increased air temperature of the conservatory may be used at all times. When the occupants are out the conservatory will charge up the store, when they are in it will provide prewarmed ventilated air partially warmed by the store.

Natural convection is unlikely to be sufficient, and a fan will be necessary to drive the air through the store. The air may emerge too cool and the conservatory will certainly not be able to provide sufficient heat to keep the house warm. These two problems can be solved with a warm air heating system which could entrain the ventilated air necessary. With a simple modification a typical gas-fuelled unit could be set to run with or without the heater on. The incoming air can then be warmed or not as necessary. Fuel will be saved since at all times the air entering the boiler will be at a higher temperature than the outside air. The only additional energy would be that of the fan during charging periods. This should be small.

There is a risk that in getting a house warmed to comfort conditions the slab may be warmed by the house rather than the conservatory. This is not a drawback since the incoming air at the entrance to the slab is likely to be warmer than the outside air, and the slab's contribution to the warming of the air will still be advantageous.

1.9 Proposed passive solar system for new houses

A system comprising a conservatory, concrete first floor and gas warm air heating unit will be investigated.

An ordinary conservatory, similar to those available at any garden centre, will be used. No alterations to the conservatory are envisaged. There will be an outlet from the conservatory to a plenum duct, which in turn will be connected to the ducts through the concrete floor slab.

The Concrete and Cement Association state that a precast concrete floor will cost no more than an ordinary timber floor. The output of the slab will be connected to the ventilated air input of a gas fired warm air heater, similar to that produced by Johnson and Starley.

The control system of the warm air heater will need to be changed to maximise the output and the precise alterations necessary will be investigated. Additional costs are expected to be very low since all items might normally be included in low cost housing.

It is believed that the conservatory is a desirable addition to the house and that its costs could be therefore justified on these grounds alone. The "payback period" would then relate only to the costs of additional ducting and a new control system. Provisional estimates for the additional cost of the system are of the order of £50.00 to £100.00 per house. The greates cost may be the new control system but the price of this would drop with increased production. The savings are not likely to be great, possibly of the order of £15.00 per annum. There will still be a need for substancial heat input from other sources. It is bearing these small but significant gains in mind that the system has been developed as a low cost passive solar system.

Fig(1.2) shows an outline of the proposed system with provisional operating conditions.

During the day, if the house is unoccupied, the fan will be switched on whenever the air temperature of the conservatory is higher than the air temperature of the house. The warm store will start to radiate heat to the house and the prewarmed air will warm the house.

When the house is occupied, the fan will draw the necessary air for ventilation through the slab and if the outlet temperature is below the required level, the heater will be switched on. If the conservatory air temperature is above 40^{o}C a vent in the conservatory will be opened to prevent over heating.

1.10 Intended Research

1.10.1 Investigation of the effect of orientation on solar collection in a British climate.

1.10.2 Analysis of the effect of occupancy and fuel demand.

1.10.3 Analysis by experiment and computer of the behaviour of a conservatory.

1.10.4 Construction of a floor slab and experimental analysis of its behaviour as a heat store.

1.10.5 Design of whole house system.

	Av. Air Temp/^{o}C	Global Radn/MJ/m^2	Daily sunshine /hours
Sep.	14.7	250	4.9
Oct.	11.8	218	3.4
Nov.	7.5	155	1.9
Dec.	4.9	98	1.5
Jan.	4.0	93	1.7
Feb.	4.9	159	2.0
Mar.	6.8	236	3.8
Apr.	9.4	245	4.4
May.	12.5	248	6.2

Average temperature is a ten year average 1959-68 from Kew (C.I.B.S.E.,1982a)

Global radiation is a monthly average over 9 years, 1967-75 for a south facing vertical surface at Easthampstead (Meteorological Office, 1981)

Daily hours sunshine is also for Easthampstead (Met. Office, 1981)

TABLE 1.1 Average monthly air temperatures and global radiation on a South Facing Vertical Surface.

	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
TEO(CONS)/^{o}C	26.0	21.7	14.5	9.3	8.2	12.1	17.5	20.5	23.7
TEO(WALL)/^{o}C	17.4	14.2	9.2	6.0	5.0	6.6	9.4	12.1	15.2

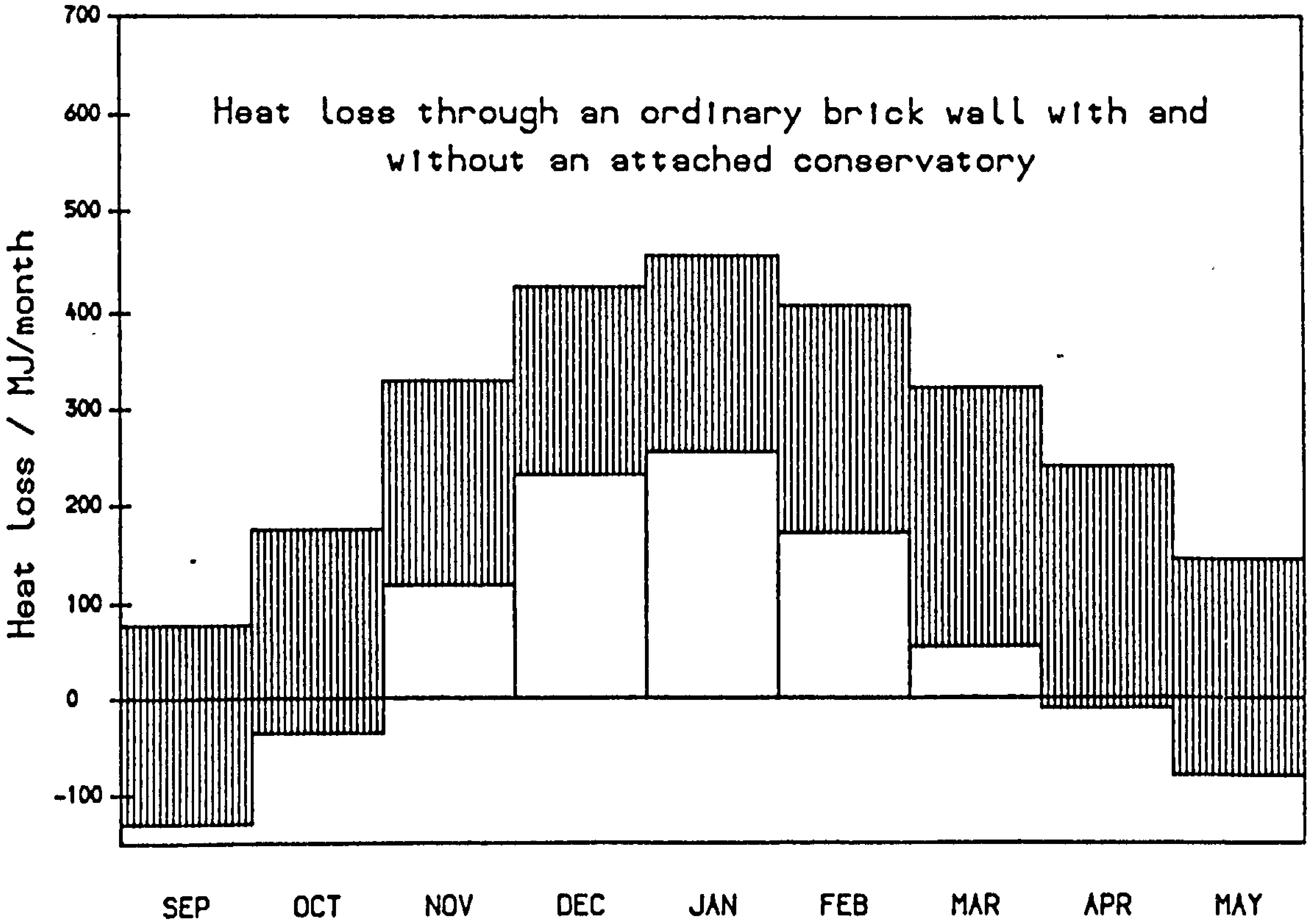
Sol-air temperatures (TEO) are monthly averages calculated from the data in Table 1.1.

TABLE 1.2 Sol-air Temperatures for a Normal South Facing Wall and the Same Wall with a Conservatory.

	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
TC/^{o}C	19.3	17.1	13.7	11.4	10.7	12.0	14.1	15.8	17.9

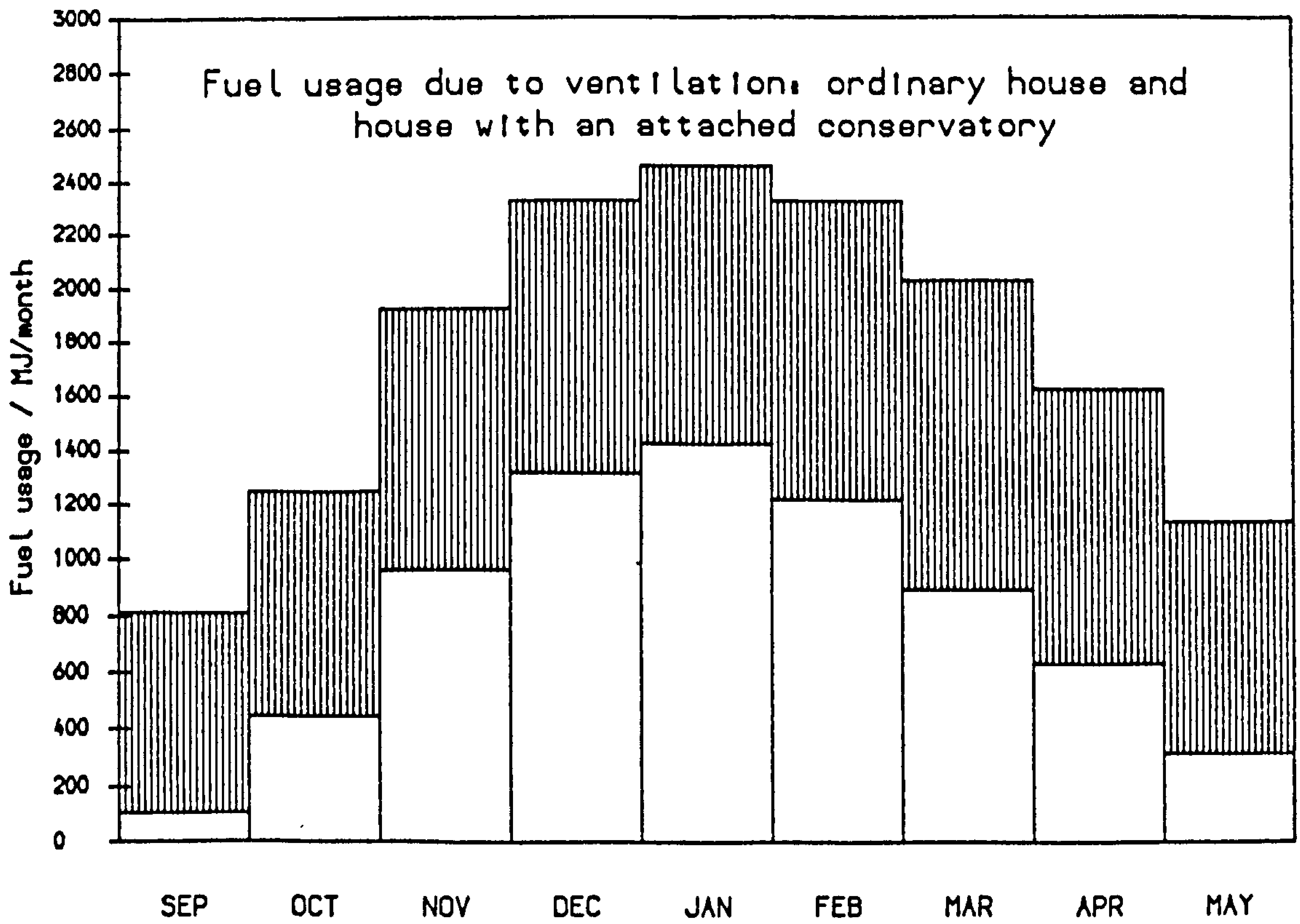
Conservatory temperatures (TC) are monthly averages calculated from the data in Table 1.1

TABLE 1.3 Expected Average Conservatory Temperatures.



a)

Upper line is without conservatory, lower with conservatory



b)

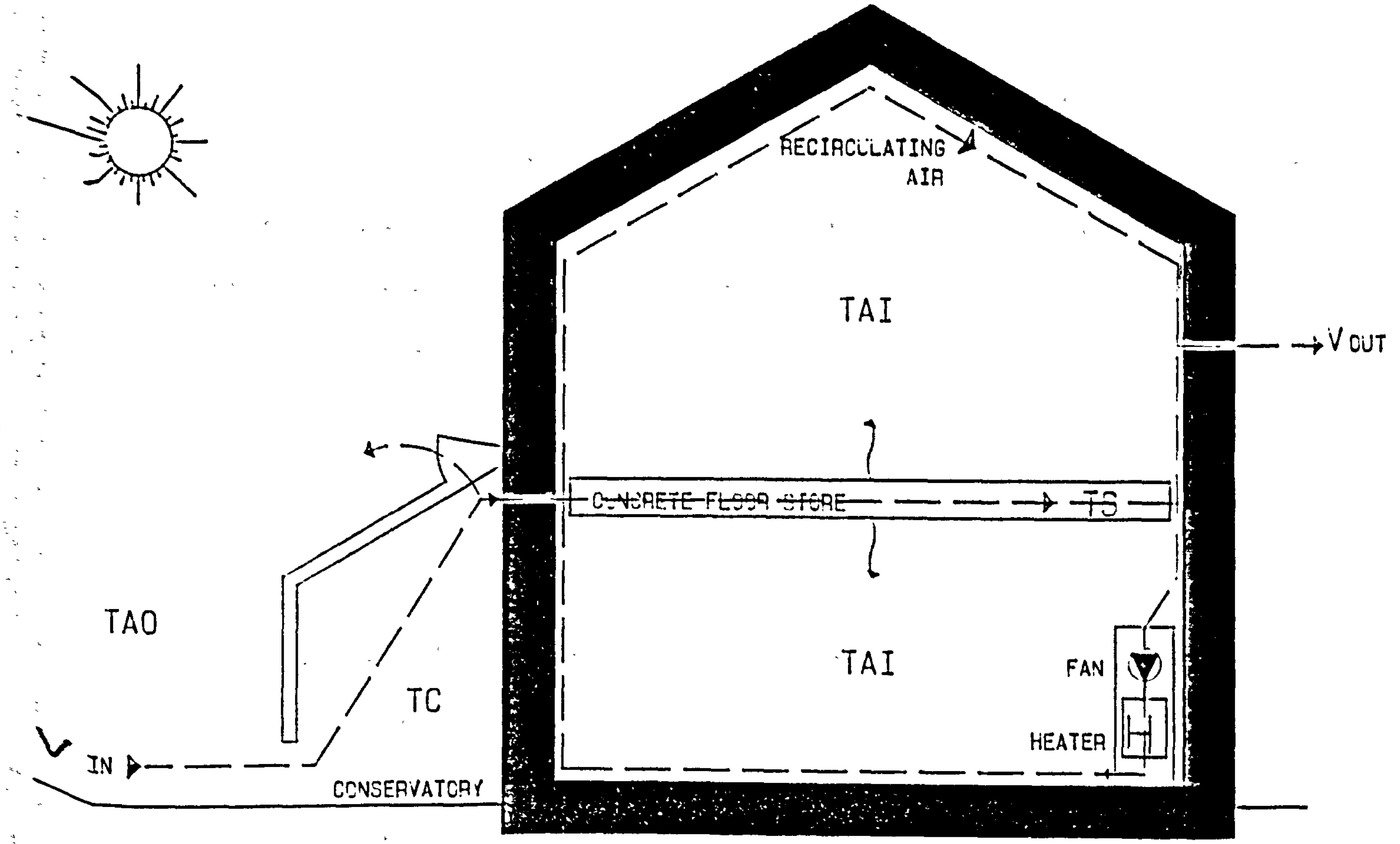
Shaded area : nett saving with conservatory

Figure (1.1)

SCHEMATIC OUTLINE OF COLLECTOR

TAI: INTERNAL AIR TEMPERATURE
TAO. EXTERNAL AIR TEMPERATURE
TC: CONSERVATORY AIR TEMPERATURE
TS. AIR TEMPERATURE LEAVING STORE
V: VENTILATION AIR

NOTE: NO PREFERENTIAL RETURN OF AIR TO THE CONSERVATORY



OPERATING CONDITIONS

FAN ON WHEN:		HEATER ON WHEN:	
UNOCCUPIED	OCCUPIED	UNOCCUPIED	OCCUPIED
TS < 30 C TAI < TC TAO < 20 C	ALWAYS	NEVER	TS < 20 C

VENT OPEN: TC > 40 C

FIG (1.2)

CHAPTER 2 REVIEW OF RELATED WORK

2.1 Introduction

Until recently, little thought had been given to the passive solar gain that a conservatory may contribute to the building. Whilst there is now a greater awareness of the possible benefits of a suitably orientated conservatory, there are few examples of them in use within the British Isles which have been monitored.

2.2 Conservatories and New Houses

A great deal of experimental and research work has been carried out upon the integrated design of conservatories by Cedric Green. The Delta House in Suffolk (Green,1979) is a highly insulated timber building with a two storey conservatory. Thermal storage is provided in the form of a black tiled concrete raft floor and concrete block walls around the service rooms in the core of the building. During the day the sun warms the interior directly. Air thus warmed is convected around the house returning through the stairwell. Evaluation of the house from January to April 1975 showed that 43% of the heating of the house, including the conservatory, was provided by the sun, but if the house alone is considered the contribution is 23%.

It is useful to note the higher figure if the conservatory is considered as part of the house. This figure is valid since the conservatory provides an extension to the living space which is usable for a large part of the year. The attached conservatory can be considered desirable for this reason alone.

The Solar Heated Experimental Dwelling Project (SHED Project) (Greeen, 1979) and (Green & Riley, 1983) leads on from the work done on the Delta House. The SHED Project was designed as a passive solar laboratory to test various types of heat stores and control strategies, considering the conservatory to be a low temperature buffer space with higher temperature solar air heating within it. Half of the wall between the conservatory and the room is glazed allowing for direct gain, whilst the remainder is equipped with various solar collectors. The results show an energy saving of 250 to 360 MJ/m^2 of vertical plane for the direct gain system and between 470 and 500 MJ/m^2 of vertical plane for the system using some form of thermal storage for the Sheffield climate.

A few schemes, including conservatories, are described by Lebens (1980). The Maison à Ginestas at Aude, France, is a house built on a limited budget by Michel Gerber using the principles of direct gain, indirect gain and conservatory. The building is of particular interest since the conservatory is carried up to just below first floor window height. The floor continues out to the glazing. Beneath the glass on the first floor are water filled steel drums cut off from the house by roller shutters on sunny winter days. At night the shutters are placed between the glazing and the drums to reduce radiation losses to the sky and enhance the heat transfer to the room. During the summer the process is reversed to improve cooling.

Lebens (1980) also describes some of the prizewinners of the European Passive Solar Competition. The simple house with a conservatory of Lundgaard, Rotne, Sorenen, Steenson and Grimmig at Thuro, Denmark has a sensibly thought out zoning for the different needs of the occupants and the climatic changes throughout the year. The single dwelling for Edinburgh, by Hewitt and Harrison, uses a large conservatory which becomes an integral part of the dwelling. The construction is of timber frame to minimize the fabric losses, with most of the windows to the south side. Neither of these examples include any form of storage hence the contribution of the conservatory may be somewhat debatable given only morning and evening occupancy: the house being empty during the day. However, both groups of designers seem to be aware of this and have approached the problem from different directions. They have used the conservatory as an extension of the living space -in the case of Edinburgh, a habitable area throughout most of the year -and in the Danish example as a tool for extending the short northern summer and as a collector for warming a secondary zone of the house.

Many problems arise in the use of conservatories for high density housing, not least of which is overshadowing. This problem is exacerbated if the houses are to be terraced. An interesting attempt to solve this problem is a design by Malcolm Newton described in (Newton, 1983 and R.I.B.A.,1983). The novel feature of these urban houses is the incorporation of a first floor conservatory. The houses, which run on an east-west axis, include a large south facing glazed roof forming the basis of an integral sunspace. Combined with this , Newton has reversed the traditional ground and first floor so that the main living areas maximize any solar benefits. The designer claims that energy consumption is reduced by two thirds for typical occupancy as a result of passive solar gain and the conservatory's effect as a buffer space improved insulation and a tight building form. It is difficult to estimate the contribution of each measure. It is certainly wise to insulate well any new house today and the most recent building regulations enforce this. The argument that a tight building and a conservatory as a buffer space enhance the building's energy saving characteristics does not seem realistic. A tight building has little need for a buffer space between the houses since neighbours houses are likely to be at a similar temperature. Greater savings would be made if the conservatory were on an external wall.

Similarly, the Peterborough solar project (Peterborough Development Corporation, 1982) is an attempt to produce local authority housing which obtains a portion of its energy from the sun. The house has a totally glazed southern first floor and air ducts for solar warming on the roof. At the ground floor is a conservatory which preheats the air for the solar collectors and warms the air for ventilation. The whole system is controlled by a microprocessor which measures a variety of temperatures around the house and chooses the most suitable heating mode from eight options. The house is also particularly well insulated.

The designers claim that the house is revolutionary since it uses air as a heat transfer medium, although little new seems to have been incorporated. It is also claimed that it will receive 50% of its energy from the sun. This seems exceptionally optimistic even though the microprocessor may make a great contribution by optimizing whatever energy there is. The house however is well designed and appears to work well as an integral solar collector.

It remains to be seen what the likely pay back period will be, especially since the energy demand will be greatly reduced by the inclusion of effective insulation. Should the dwellers wish to use the conservatory throughout the year they may decide to heat it, thus counteracting any benefits that may be obtained by reduction of the whole house heating demand.

2.3 Conservatories for non-domestic buildings

Non-domestic buildings are outside the scope of this work but many of the advances in this field are of use to domestic buildings. The use of a conservatory or the incorporation of its principles within the design are particularly relevant in the design of non-domestic buildings because of the common occupancy pattern of this type of building. In schools and offices especially, this type of solution seems very apt since most of their usage is during the day. This makes heat storage unneccesary.

An interesting recent example is the Locksmith School (Architects Journal, 1983a). In this building, the south face has been made into a conservatory which will act as collecting space for solar energy and additionally forms a buffer space between the outside and the carefully controlled environment of the classrooms.

The design has taken careful note of the fact that whilst the school is occupied, the heat loss is primarily due to ventilation. Solar energy is therefore used, via the conservatory, to preheat the incoming air for ventilation. This is achieved by heating the classrooms with fan coils over which is drawn fresh air from the conservatory. This seems to be a very realistic approach for maximizing any solar input for this school, since the conservatory provides an instantaneous contribution to heating whenever the sun shines.

The architects have used the conservatory very well: it is not only a solar collector but acts as a primary circulation link for the school, and houses any craft facilities associated with the classroom.

Also worthy of mention is the Tabkro Building (Architects Journal, 1983b) by the Geoffrey Thorpe Practice and Engineers Comber Building Services. Whilst not appearing to have a conservatory, it embodies many of its features. The whole of its south elevation is glazed with two layers of glass about 900mm apart, separated by a lightweight venetian blind. The outer glass is clear and the inner tinted. There are grills at top and bottom of the gap where air may enter and leave to be warmed by the sun.

There is little storage apart from the 900mm of concrete floor and the building is lightweight hence there is little storage of the solar gain. This, however, is not too bad since it is offset by the simplicity of the system and the likely occupancy pattern of the offices.

It is inevitable that the contribution of the sun will be limited because of the good insulation and compact shape of the building. This contribution is likely to be of the order of 5% of the seasonal heat demand of the building.

2.4 Conservatories for rehabilitation

Ferraro (Turrent, Doggart and Ferraro, 1980) describes conservatories as the "most promising solution for passive solar retrofit". It is here that most opportunities lie for simple passive solar design. It is, however, probably where the least work has been done. At its most elementary, the addition of a conservatory on any side of the house can make a valuable contribution to the energy saving of a house. If however the conservatory is well orientated, its usefulness is greatly increased.

Many interesting examples are described by Lebens (1980), in particular the multi-storey housing in Bath designed by the Energy Design Group. The design, which is for a typical Georgian terrace house in Bath with south facing exposure, consists of a solar glazed skin, the purpose being to transform medium and high rise buildings into energy efficient buildings. The house is covered with a combination of Trombe walls, conservatories and window box greenhouses. The conservatories work in a simple manner, by allowing warm air to flow from the top into the rooms behind. The Trombe wall is fairly standard although it is double glazed and has a heat mirror layer between the panes. The whole system is well integrated and not ugly and although the ideas may seem somewhat excessive, if the system could be made more modular and therefore mass produced, it may be a useful tool in rehabilitation design.

A survey of Cambridge housing (Hawkes & Sousa, 1984) was undertaken with the purpose of quantifying the factors relating to the exploitation of solar energy by retrofit or rehabilitation. These factors were identified as being primarily orientation and obstruction. The results showed that given limits on orientation of within 45 of south, 57% of dwellings were found to have one favourable major facade, of which 76% lost no more than 20% of the possible solar radiation through the heating season. The report shows, more importantly, that specific groups of houses have greater potential for passive solar systems, in particular owner-occupied post 1919 houses. These tended to be semi-detached or detached and built at low densities. Additionally owner-occupiers were more receptive to passive solar systems than any other group. Hawkes and Sousa suggest that for this particular group of houses, the most obvious solution is that of the low cost standard package conservatory.

CHAPTER 3 ORIENTATION AND SOLAR GAIN

3.1 Introduction

All buildings are passive solar collectors. They will all benefit from solar radiation to a certain extent. The actual gain to the building is dependent upon the construction of the building and its layout. The total effect of the sun upon the building depends upon the climate and the orientation of the building. In this chapter these effects will be examined for the heating season, September to May. At other times of the year the sun may have a useful contribution to make, but its effect is not as critical at the design stage.

3.2 Weather Data

Weather data for the years 1959-1968 from Kew were obtained on magnetic tape from the Meteorological Office. The data consist of hourly readings of 25 variables including the diffuse radiation measured on the horizontal surface in W/m^2, the direct (beam) radiation measured normal to the sun's rays in W/m^2. The tapes include daily sums/averages for all of the measurements. An hour by hour average year was created from the ten years of data.

3.3 Length of the day

To calculate the length of the day the angle of declination of the earth must be known. Using the formula of Cooper (Duffie and Beckman, 1974),the declination is given by:

$$\delta = 23.45 \sin(360(284+n)/365) \qquad (3.1)$$

The length of the day T in hours (Duffie and Beckman, 1974)

$$TD = (2 \arccos(-\tan L \tan\delta))/15 \qquad (3.2)$$

n being the number of the day. (Jan 1st = 001)

3.4 Solar Data

Fig (3.1) shows the length of the day in the heating season, September to May, and the cumulative monthly hours of daylight at Kew . Beneath this is shown the number of hours of unclouded sunshine received per month. This is considerably lower than that possible, as low as about 45 hours total for the month of December. The proportion of the sun that is received varies between 20% of the possible total in early winter, to 40% at the beginning and the end of the heating season. Hence, not only does the beginning and end of the heating season have longer days, but the proportion of the time that the sun shines is higher.

Fig(3.2) shows the variation in direct and diffuse solar irradiation through the heating season from ten years of data. The amount of diffuse irradiation per month varies similarly to the length of the day. Similarly, the diffuse irradiation varies little from year to year, usually within 10% of the average. The direct radiation shown is the integrated beam radiation. No surface will receive this radiation, it is an indication of the intensity of the direct radiation at different times of the day and year.

The direct solar radiation varies similarly through the heating season but by no means as uniformly. The variation from year to year is far greater, the difference being as much as 60% of the average. The proportion of the radiation that is direct varies little through the heating season, however there is a large variation from year to year. It would appear that overall the proportion of direct radiation is between 50% and 60% of the total radiation.

As may be expected, the solar input to a building will be greatest at the beginning and end of the heating season. This is true not only for the duration of the solar input but also for the magnitude of the irradiation However, there is no evidence to suggest that during the mid-season the proportion of energy that is received by direct radiation is lower. Curiously, in the mid-season the proportion of time that the sun shines is lower but the energy received is directly proportional to the possible number of hours of solar input, suggesting that when the sun shines in the winter, it is stronger than during autumn and spring.

A significant proportion of the solar input gained through the year is in the form of diffuse irradiance. This is true not only in terms of the total energy received but more significantly, of hours of diffuse irradiance compared to the total number of hours direct irradiance. During all daylight hours the building is benefiting from diffuse irradiance whilst the total time of direct irradiance is of the order of 20% - 50 % depending upon the time of year.

3.5 The Position of the sun

To quantify the effect of the orientation of a building, it is necessary to calculate the position of the sun at any one time for any place.

The altitude and azimuth may be calculated according to Duffie & Beckman,1974,

$$\sin\alpha = (\cos\phi \times \cos\delta \times \cos\omega) + (\sin\phi \times \sin\delta) \qquad (3.3)$$

$$-\sin\epsilon = (\cos\delta \times \sin\omega)/\cos\alpha \qquad (3.4)$$

The solar azimuth is taken as zero if the sun is in the north, 90 if the sun is in the east.

The latitude is taken as positive for the northern hemisphere and negative for the southern hemisphere. The hour angle is zero at noon and is given by

$$\omega = (\text{hour}-12) \times 15^{o} \qquad (3.5)$$

The angle of a vertical surface in relation to the sun is

$$Y_s = \epsilon - Y \qquad (3.6)$$

The wall azimuth Y_s is the horizontal angle between the sun and the wall. The angle is positive when measured clockwise from the perpendicular and negative when measured anticlockwise (C.I.B.S.E. 1982).

3.6 Design Solar Radiation Intensity

The total solar radiation reaching the surface of a building is made up from three sources,

1) Direct radiation, which comes directly through the atmosphere.

2) Diffuse radiation, which is scattered by the atmosphere.

3) Ground reflected radiation, a proportion of direct and diffuse that is reflected from the ground.

The intensities of the direct and diffuse radiation depend upon the latitude and height of the locale, the altitude and azimuth of the sun and the sky clarity.

From (C.I.B.S.E. 1982) the design total irradiance on a horizontal surface is given by

$$I_{THd} = I_{DHd} + I_{dHd} \qquad (3.7)$$

i.e. the sum of the design direct irradiance and the design diffuse irradiance on a horizontal surface. The design direct irradiance is given by

$$I_{Dd} = k_a \, k_D \, I_D \qquad (3.8)$$

and the design diffuse by

$$I_{dd} = k_a \, k_d \, I_d \qquad (3.9)$$

Hence equation (3.7) becomes

$$I_{THd} = k_a \, (k_D \, I_{DH} + k_d \, I_{dH}) \qquad (3.10)$$

Similarly for vertical surfaces

$$I_{TVd} = k_a (k_D I_{DV} + 0.5k_d I_{dH} + 0.5k_r I_{TH}) \qquad (3.11)$$

For north facing vertical surfaces 0.5k becomes 0.4k and for north-east and north-west surfaces 0.45k .

Fig A2.23 of the C.I.B.S.E. guide (1982) shows the design maximum irradiances for South-East England. These are the irradiances that are likely to be exceeded for 2.5% of the time and are from Kew weather data 1959-68. The following correction factors were used for equations (3.10) and (3.11)

$k_a = 1.0$

$k_r = 0.2$

k_D and k_d varied from month to month e.g. September $k_D = 0.88$ and $k_d = 0.97$.

This diagram is a good starting point from which to examine the effect that orientation has upon a building's behaviour as a passive solar collector. It must be remembered that the data have been produced with an eye to the avoidance of overheating. Much of the noticeable trends are due to the geometry of the building in relation to the sun, rather than observed weather data.

For north facing surfaces very little direct sunlight strikes the surface during the day except at an obtuse angle before 06.00 h and after 18.00 h from April until August where there is a noticeable peak. For the rest of the year there is a mild peak at midday due to the diffuse intensity, the greatest being for July and May.

For an east facing surface there is a distinct peak before midday, the greatest value being in June and then a steady decrease afterwards with the highest level being for July and May. The reverse is true for west facing surfaces.

The peak occurs at midday for all months on south facing surfaces, the highest value being for September and March. The variation throughout the year is not great at about 200 W/m^2

A horizontal surface receives the maximum irradiation at midday in June. The minimum occurs in December.

Orientation affects the irradiance on a surface not only in intensity but also in the time that it occurs. For a vertical surface in June, the peak irradiance is very similar for all orientations between 90° and 270° but the time varies between 07.00 h and 19.00 h. This suggest that not only south facing surfaces are susceptible to overheating. Orientation becomes more critical during the rest of the year. On a south facing surface, the irradiance is fairly constant throughout the year but moving towards the east or west, the total irradiance decreases to its minimum in December. Hence overheating can occur on a south facing surface at any time of the year but is unlikely on east or west facing surfaces suring the winter months.

3.7 Actual Solar Radiation Intensity

Equations (3.10) and (3.11) can be used with data for basic irradiances I_{DVd}, I_{DHd} I_{dVd} I_{dHd} from (C.I.B.S.E 1982) for many circumstances using various correction factors where:

I_{DVd} : design direct irradiance on a vertical surface

I_{DHd} : design direct irradiance on a horizontal surface

I_{dVd} : design diffuse irradiance on a vertical surface

I_{dHd} : design diffuse irradiance on a horizontal surface.

However, raw weather data have been used, hourly diffuse radiation on a horizontal surface I_{dH} and direct radiation on the beam I_{Dbeam}. Hence many of the correction factors are not required. Equations (3.10) and (3.11) become:

$$I_{TH} = I_{DHd} + I_{dH} \tag{3.12}$$

$$I_{TV} = I_{DV} + 0.5\ I_{dH} + 0.5\ k_r I_{TH} \tag{3.13}$$

Altering this for beam radiation and the solar intensities upon specific surfaces:

$$I_{TH} = (I_{Dbeam} \times \sin\alpha) + I_{dH} \tag{3.14}$$

$$I_{TV} = (I_{Dbeam} \times \cos\alpha \times \cos\gamma_s) + 0.5\ I_{dH} \quad +$$

$$0.5 \times k_r(I_{dH} + (\sin\alpha \times I_{Dbeam}) \qquad (3.15)$$

Using equations (3.14) and (3.15) combined with equations (3.3) and (3.4) it is possible to determine the total radiation upon vertical surfaces and horizontal surfaces

3.8 The effect of orientation

Figs (3.3) - (3.10) show the total solar irradiance through the day falling on vertical surfaces of orientations at 45° intervals. In each case, the upper graph was produced from the averaged hour by hour weather data. The lower graph shows the data for 1963 which are regarded as a typical year (C.I.B.S.E. 1982). The data for both cases has been averaged for 3 days around the 21st of each month considered, in an attempt to reduce the likelihood of unrepresentative days. Ideally every day would have been shown but due to lack of space this was not possible. The data for 1963 is more representative than the average year but the average is shown for the purposes of comparison. Averaging over three days for 1963 reduces the chances of unrepresentative hours. This has been done for the average year for completeness.

From Fig (3.3) (the solar irradiance on a northern vertical surface) it can be seen that there are no peaks in the early morning and evening since the summer has not been considered. The curves are fairly flat with the peak in May and the minimum in December. The peak varies between 12.00 and 15.00 h with the overall intensity being steady between 11.00 and 15.00 h for most months.

The north-east facing surface, Fig (3.4), is very similar to the north with little noticeable time-shift.

The east facing surface, Fig (3.5), has a noticeable diurnal peak at around 11.00 h with the greatest peak in April.

The west facing surface, Fig (3.9), is almost a mirror image of the east except that the pre-midday levels on a western surface are lower than the post-midday levels throughout the year. This suggest that the diffuse intensity is greater in the afternoon than in the morning.

The south-east, south and south-west facing surfaces, Figs (3.6), (3.7), (3.8) are very similar. There is little or no time difference in the peak values for the three orientations. The overall curves are fairly flat between 1100 and 1400 hours. The solar irradiance levels tend to fall into 3 distinct bands:

1) November, December and January,
2) October, February and March,
3) September, April and May.

with the months behaving similarly within each band.

The north west surfaces are similar to those of the north east except that there is a peak at about 16.00 for September, April and May.

As can be seen, the orientations between the south east and the south west vary little in both intensity and time.

The maximum intensities on surfaces facing east and west are again similar. They are also similar to that of a south facing surface. However, the irradiance peaks are sharper and shorter, generally between one and two hours. The total energy received is lower. This is most noticeable for the months of September, April and May. The overall curve and total irradiance is very close to that of the south for the months of November to January.

There is a noticeable reduction in the received irradiance for surfaces facing north-east to north-west. Expressed as a percentage of the total irradiance on a south facing surface the irradiances are:

about 50 %: September

50 - 60 % : April, October

60 - 70 % : November, December, January, February, May

about 75 %: March.

The reasons for this are probably the increased effect of the diffuse component of the solar radiation on surfaces away from the south. Obviously, when the weather is cloudy, all surfaces are going to receive a similar proportion of solar radiation, since the diffuse component approaches 100% of the total radiation. However the diffuse component is a much smaller proportion of the larger irradiance on sunny days.

Using data from Table A2.27 (C.I.B.S.E. 1982) fig (3.11) shows the percentage of radiation upon a horizontal surface that is diffuse on sunny days, i.e. those in which the radiation levels are exceeded 2.5% of the time. As the sun rises, so the level of direct radiation increases, thus reducing the proportion diffuse radiation. This proportion increases generally through the year i.e. June - December, but not proportionally.

The same relationship is shown for vertical surfaces in fig (3.12). In this case the proportion increases to a maximum at noon, coinciding with the time of maximum solar radiation. Although the months fall into the same order for each hour they do not fall into completely logical order through the year since June is out of place.

Much of the relationships of these graphs is due to the position of the sun and the lower levels of diffuse radiation received on the vertical surface, accounting for the lower overall proportion on the vertical.

There is a distinct trend through the day for all months. The proportion of diffuse radiation received on a vertical surface increases towards noon and decreases after noon. This suggests that the orientation of the vertical surface is of importance. Fig (3.13) shows the diffuse radiation as a proportion of the total radiation for each orientation. In each case the maximum level of radiation on any orientation regardless of time was considered. For all months, the diffuse proportion is very high for north facing surfaces (50 - 65%). The level is similar for north-east surfaces for the months of October to February but shows a marked decrease for the rest of the year (8 - 17%). This is because these surfaces are now receiving some direct sunlight. The levels are fairly similar on the east but on the southern surface the months of April to August have higher levels (20 - 25%) than the rest of the year (8 - 13%). This is in part due to the altitude of the sun.

On sunny days, the orientation of a building becomes more critical but not to the same degree through the year. In December, when the sun is low the proportion of diffuse radiation that a surface receives is always low for surfaces from east through south to west. Moving towards the equinox, the proportion of diffuse radiation increases for the whole day but to a lesser degree on surfaces east and west of south and decreases on surfaces north of east and west. For the rest of the year the trend is reversed, the proportion of diffuse radiation increases for surfaces east through south to west. This suggests that on sunny days, the orientation of a surface is less critical at the beginning and end of the heating season.

Since most houses, other than back to backs, have two opposing vertical surfaces exposed, it is of interest to note the cumulative totals for the two opposing surfaces. Figs 3.14, 3.15, 3.16, 3.17 show north and south, north-east and south-west, east and west and north-west and south-east. These figures show the sum for the opposing surfaces.

The curve for north and south, fig (3.14), is a bell shaped curve with the maxima occurring at midday and the curve being fairly flat between 1100 and 1400 hrs. As would be expected the curves are very similar to those shown in Fig (3.7) for a south facing surface, since the north facing surface makes small contribution.

East and west vertical surfaces, fig (3.16) ,show two maxima at 1000-1100 hrs and 1400-1600 hrs. The afternoon being the greater of the two due to a higher level of diffuse light. There is a trough at mid-day where little light strikes the surface. The troughs are more pronounced at the beginning and end of the heating season. The maxima are not as high as for north and south.

The north-east and south-west totals, fig (3.15), and the north-west and south-east totals, fig (3.17), are very similar, being almost mirror images of one another about midday. However the north-east, south-west appears to have generally higher values. The curves are fairly flat except for September and April.

Considering the three groups of months.

1) November, December, January:

These months receive the greatest irradiance on the north and south surfaces and the north-east and south-west. The east and west receive the least.

2) February, March, October:

These months receive the maximum irradiance on the north-east and south- west surfaces. Although the north and south surfaces have a lower peak it is flatter and thus longer lasting. The east and west are lowest.

3) April, May, September:

This grouping is not as reliable as previously used since May tends to have lower and flatter maxima than September and April. The north-east and south-west is the best with north-south being very close. East and west are the lowest.

In addition to the control of orientation for the benefit of solar gain, it must be remembered that the direct sunlight can cause overheating. According to Jones (1974) the orientation of a building is most significant for buildings with much glazing. However, the orientation of a building is of little significance when there are no windows. With shading of windows the effect of orientation is less (Givoni, 1969). Givoni and Hoffman (1966) conclude that adequately insulated walls of light external colour reduces the effect of orientation on overheating still further. External colour is generally not an influence in the north European climate since overheating is rarely excessive and generally, for the typical British house, most solar overheating can be dealt with by adequate natural ventilation. This is not true of larger buildings.

3.9 Desirability of Sunlight

In addition to the wish to have sunlight enter a house for thermal reasons, there are psychological reasons for the admission of sunlight in particular visual considerations.

There are a variety of recommendations for the duration of sunlight in buildings, the most modest of which is (BSI,1945). The intention of this recommendation is that possible sunlight i.e. time when the sun may shine, although does not necessarily have to, should enter living rooms and where practicable, kitchens and bedrooms over most of the year. The criterion is a minimum of one hour daily possible sunlight over not less than ten months of the year (i.e. February to November). A clear view of the sky through a 15 degree bearing is recommended. Sunlight coming within a horizontal angle of 22.5 taken from the plane of the window is discounted. The use of equations (3.3) and (3.4) to calculate the altitude and azimuth for the limiting conditions suggests that orientations of between 71° and 289° bearing are acceptable.

Sunlight and Daylight (DOE & Welsh Office, 1971) recommends having possible sunlight on building faces in spring and summer. The

Sunlight and Daylight index suggests a minimum of three hours of possible sunlight on the 1st of March to be received at points on a building facade 2 m above ground level. Sunlight is not to be considered if it is below an altitude of 10°. The code is not intended primarily for the orientation of rooms within a building but more for general building layout, however using these suggestions, orientations of between 57° and 303° bearing comply with the code.

The draft development minimum recommendations (BSI, 1980) suggests that possible sunlight should be received at windows of living rooms and if possible bedrooms, for study and bedrooms for the elderly, in spring and autumn. The standard requires a minimum of three hours possible sunlight on March 1st. Sunlight below 5° is to be discounted and there is a limitation of a 22.5° grazing angle. Orientations of 80° to 280° are acceptable.

Hopkinson, Newton Watson and Partners (1979) is the only publication that suggests a level of probable sunlight as opposed to possible sunlight. Suggested levels are 500 hours over the year for living rooms and 400 hours for bedrooms, dining rooms and kitchens.

Using the Kew weather data for 1963 and equations (3.3) and (3.4) the total hours sunshine for the year has been calculated for various surfaces. This was done using the variable in the Kew weather data which gives the proportion of the hour that the sun shone. Fig (3.18) shows the variation of total number of hours sunshine per year for two cases:

1) no grazing angle, i.e. sunshine from 90° of the particular bearing is accetable.

2) 30° grazing angle, i.e. sunshine from 60° of the particular bearing is acceptable.

The minimum standard of 400 hours sunshine gives acceptable bearings of 41°- 344° for zero grazing angle and 71° - 314° for 30 grazing angle. For 500 hours the results are 50° - 335° and 80° - 305° respectively.

The results of all of the standards are shown in Table 3.1.

Obviously these criteria suggest greater restrictions when viewed within a town planning context, restricting the location of buildings in relation to one another. They do however suggest that for psychological reasons, it is desirable to locate living areas between towards the south between the north-west and north-east. This may be difficult for planning reasons but may be overcome by placing windows on more than one wall in a room.

3.10 Summary and conclusions

3.10.1 The orientation of a building is limited by a variety of constraints, many of which may not be controlled by the designer.

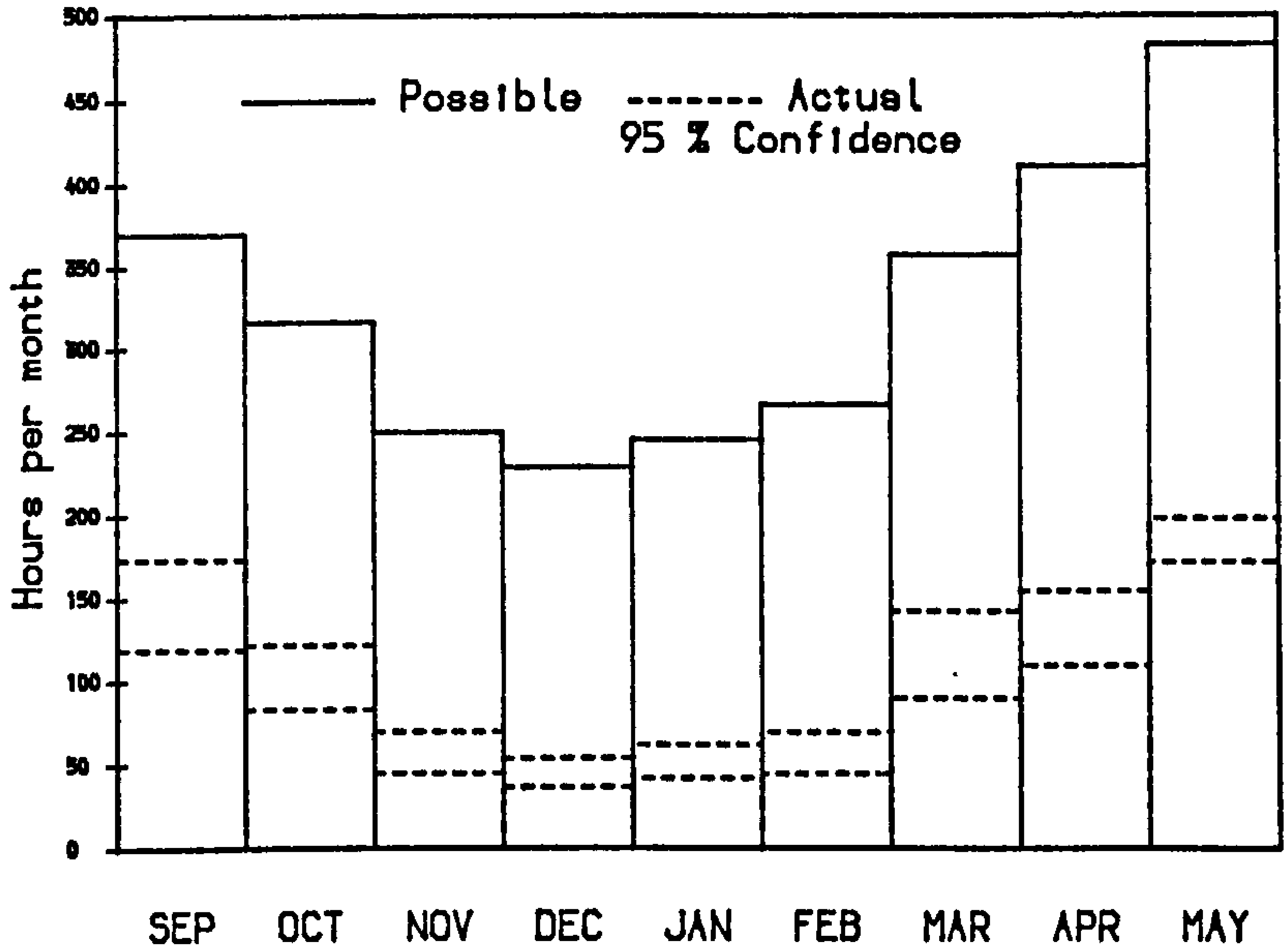
3.10.2 From the point of view of solar gain, housing is best laid out between an east-west axis and a north-west south-east axis.

3.10.3 Through most of the heating season the overall orientation is not especially important. It is the time that solar energy may be received that varies. The likely use of the house becomes therefore more critical, since it is desirable that whatever energy is available should be put to its greatest use at time of avalability.

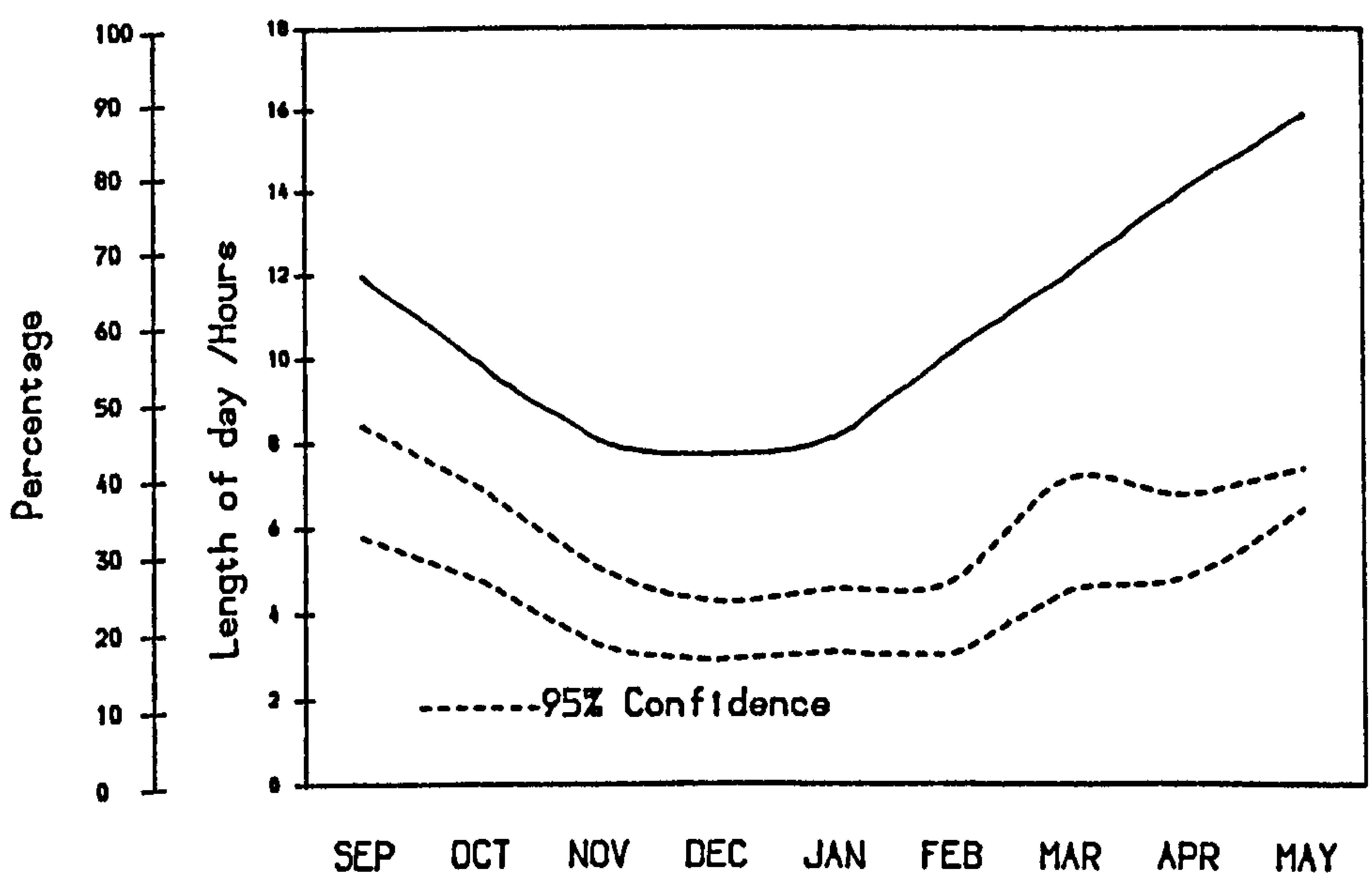
TABLE 3.1 Summary of Recommended Room Bearings.

	Living Room/° from North	Kitchen/° from North
CP3, Chap IB (1945)	71-289	-
Sunlight & Daylight (1971)	57-303	-
DD67 (1980)	80-280	-
Ralph Hopkinson, Newton Watson & Partners (1979)	50-335	41-344

CLIMATIC DATA : KEW



Possible total number of hours sunlight and actual number of hours per month



Length of day & Percentage of hours that the sun shone

Actual and percentage figures given to 95% confidence limit from Kew data 1959-68

Fig (3.1)

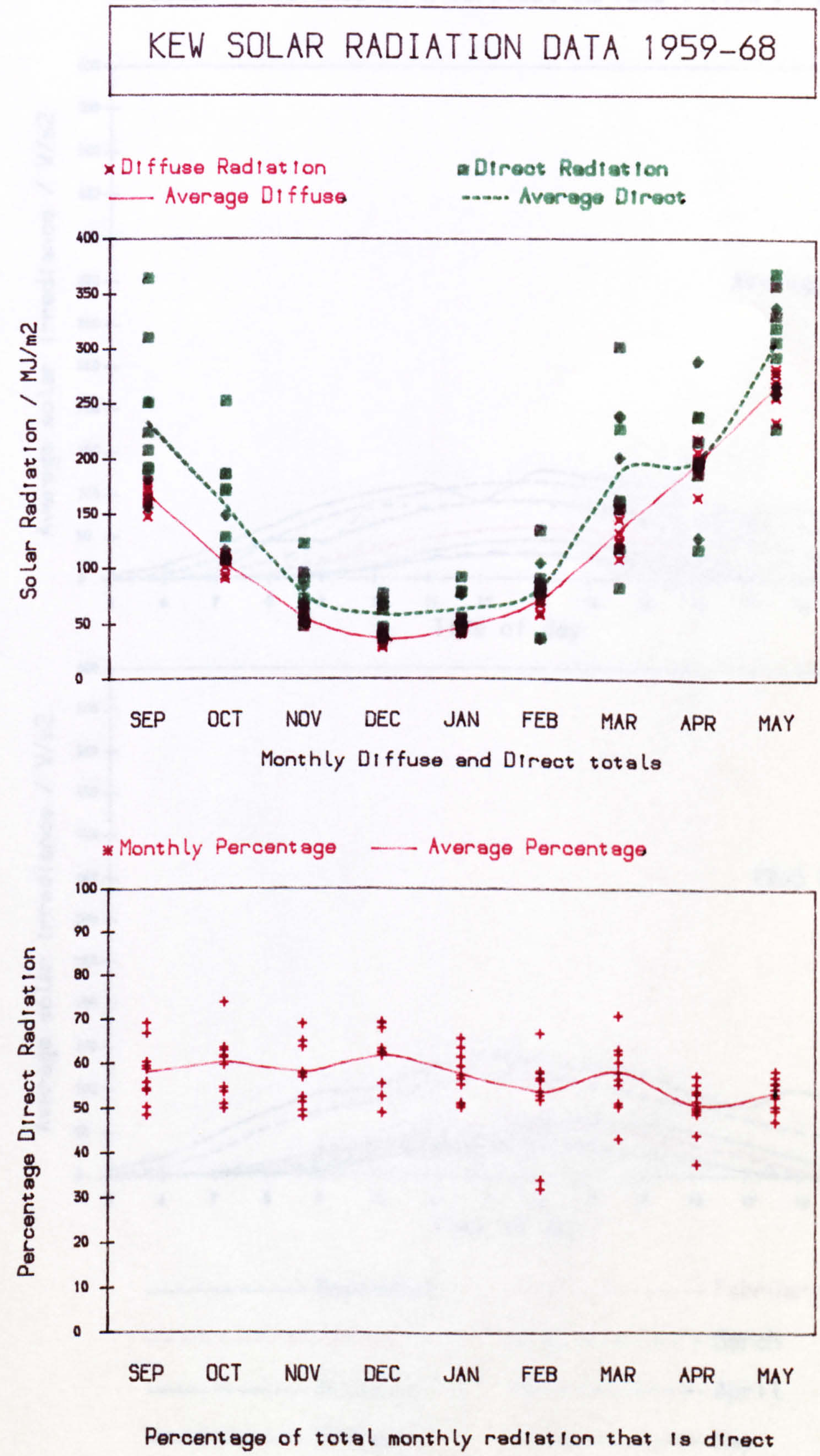
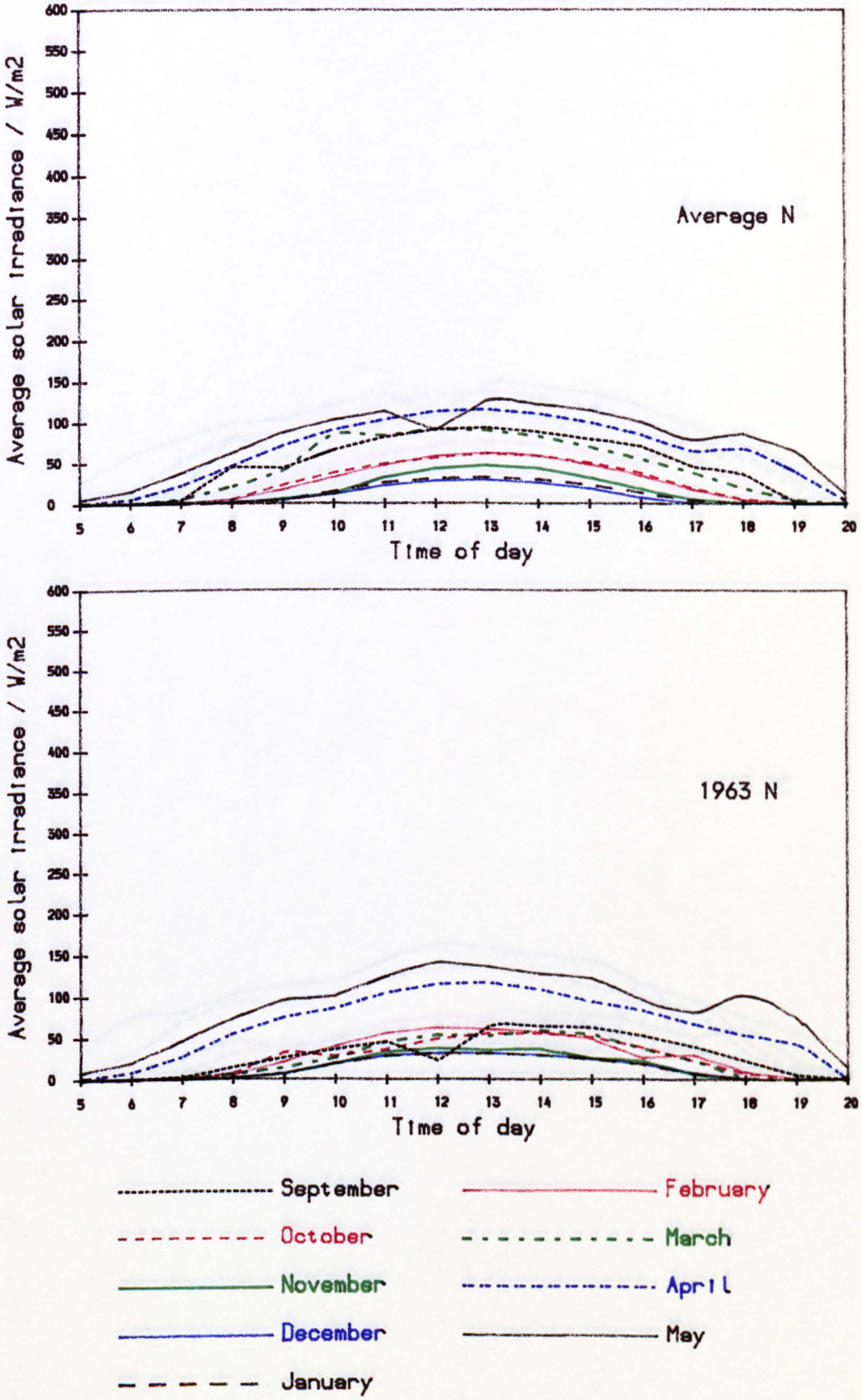

KEW SOLAR RADIATION DATA 1959-68
Diffuse Radiation
Average Diffuse
Direct Radiation
Average Direct
Solar Radiation / MJ/m2
400
350
300
250
200
150
100
50
0
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
Monthly Diffuse and Direct totals
Monthly Percentage
Average Percentage
Percentage Direct Radiation
100
90
80
70
60
50
40
30
20
10
0
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
Percentage of total monthly radiation that is direct

Fig (3.2)

Solar Irradiance on a Vertical Surface V Time / W/m2

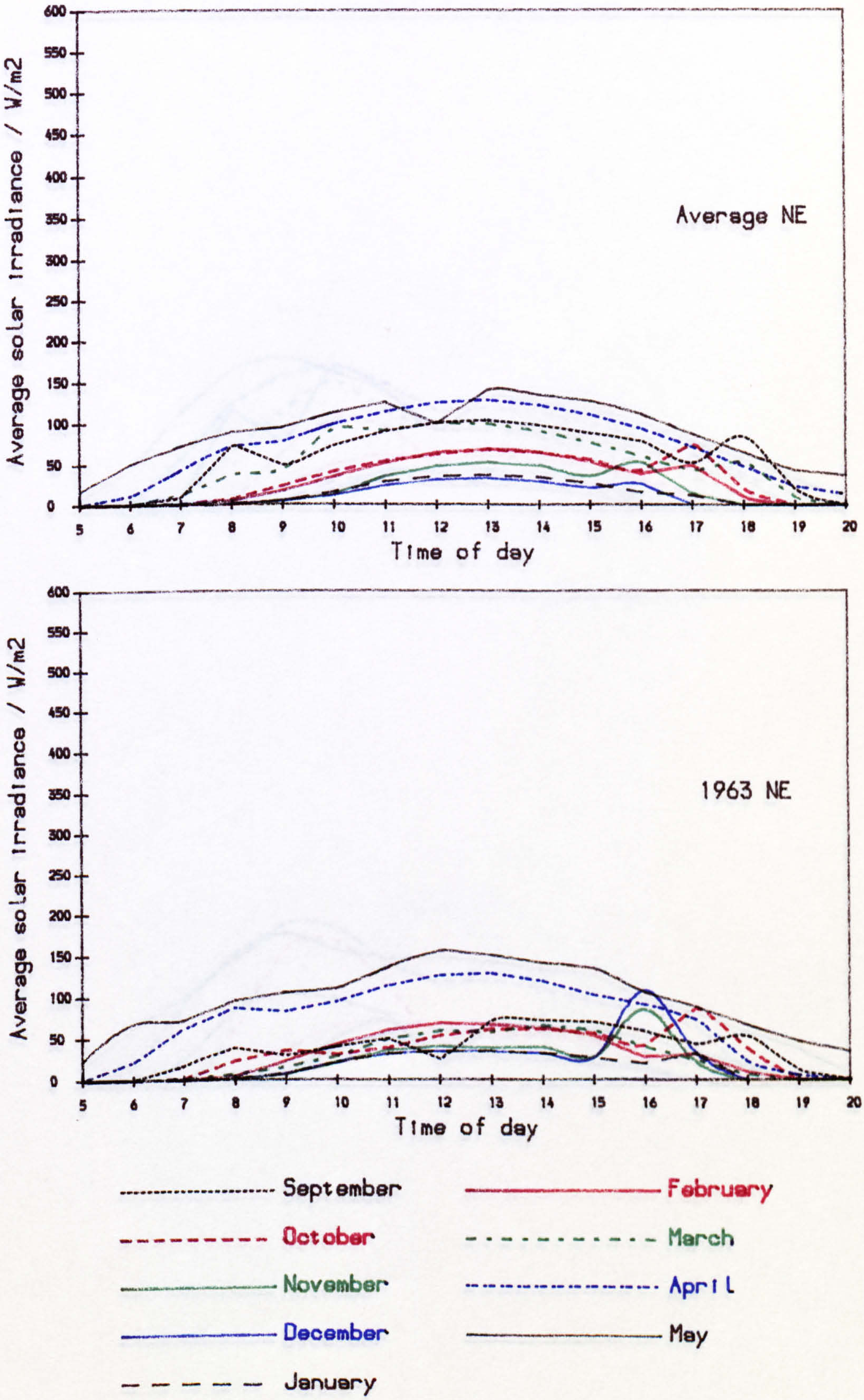


The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Figure (3.3)

Solar Irradiance on a Vertical Surface V Time / W/m2

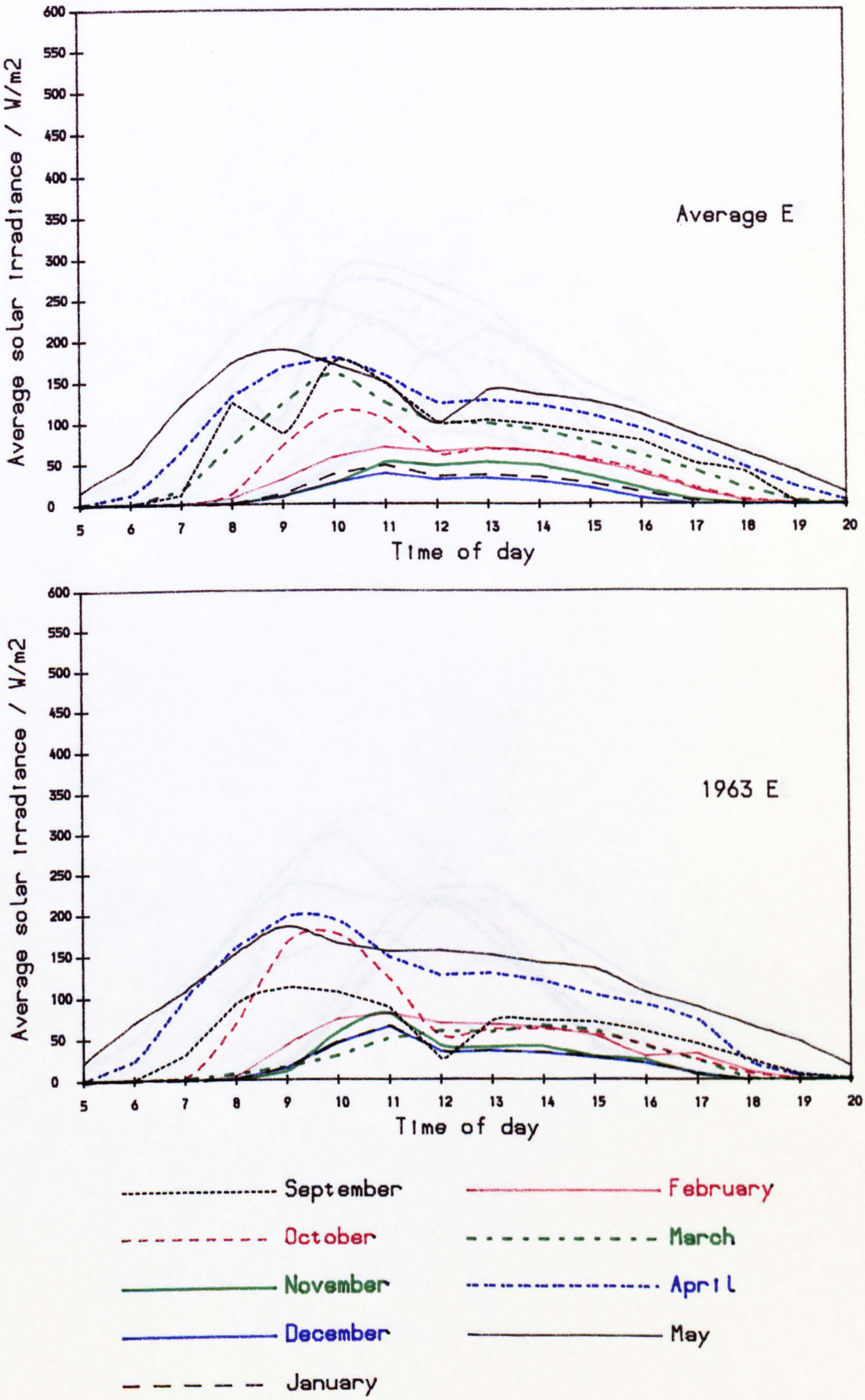


The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Figure (3.4)

Solar Irradiance on a Vertical Surface V Time / W/m2

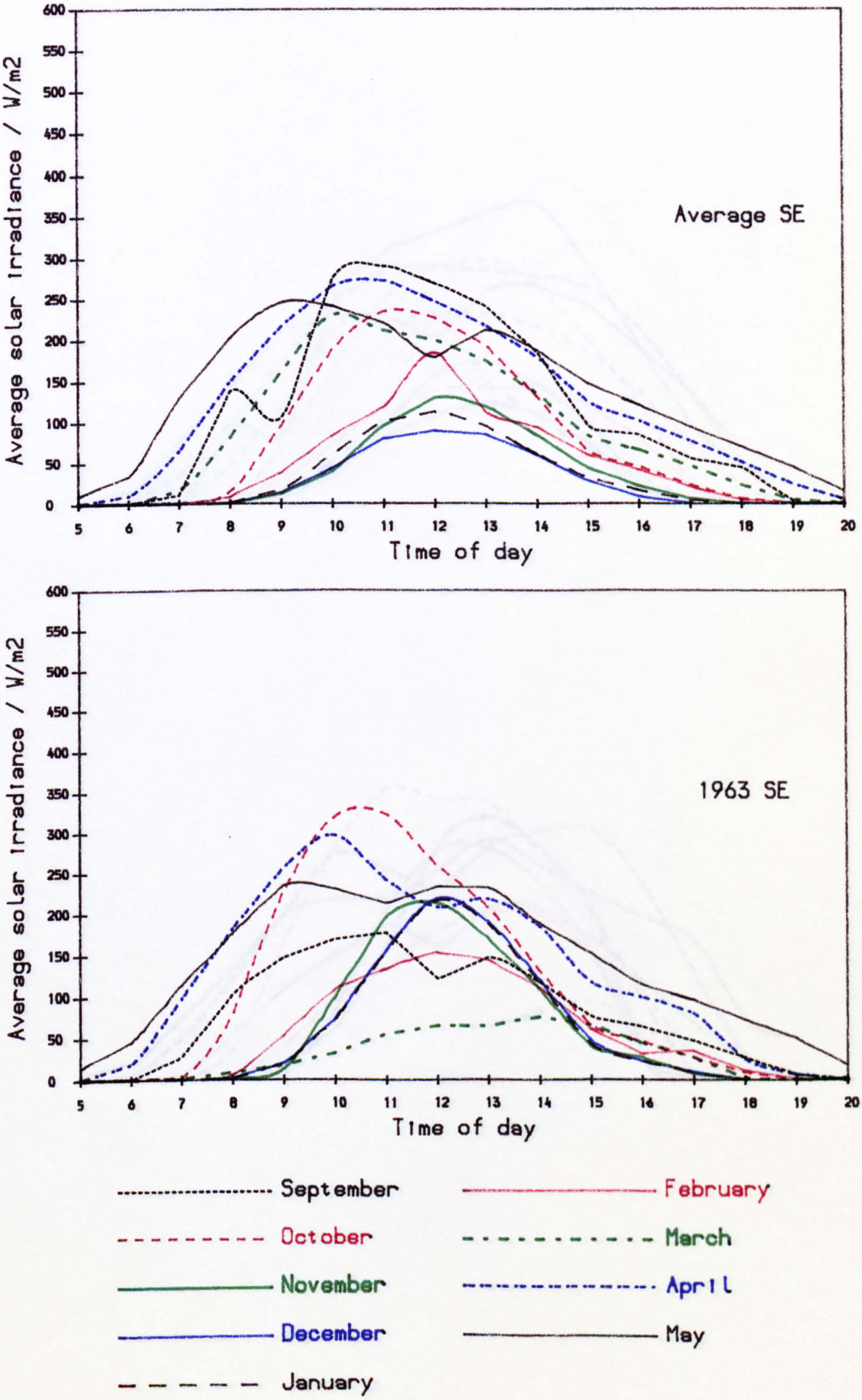


The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Figure (3.5)

Solar Irradiance on a Vertical Surface V Time / W/m2

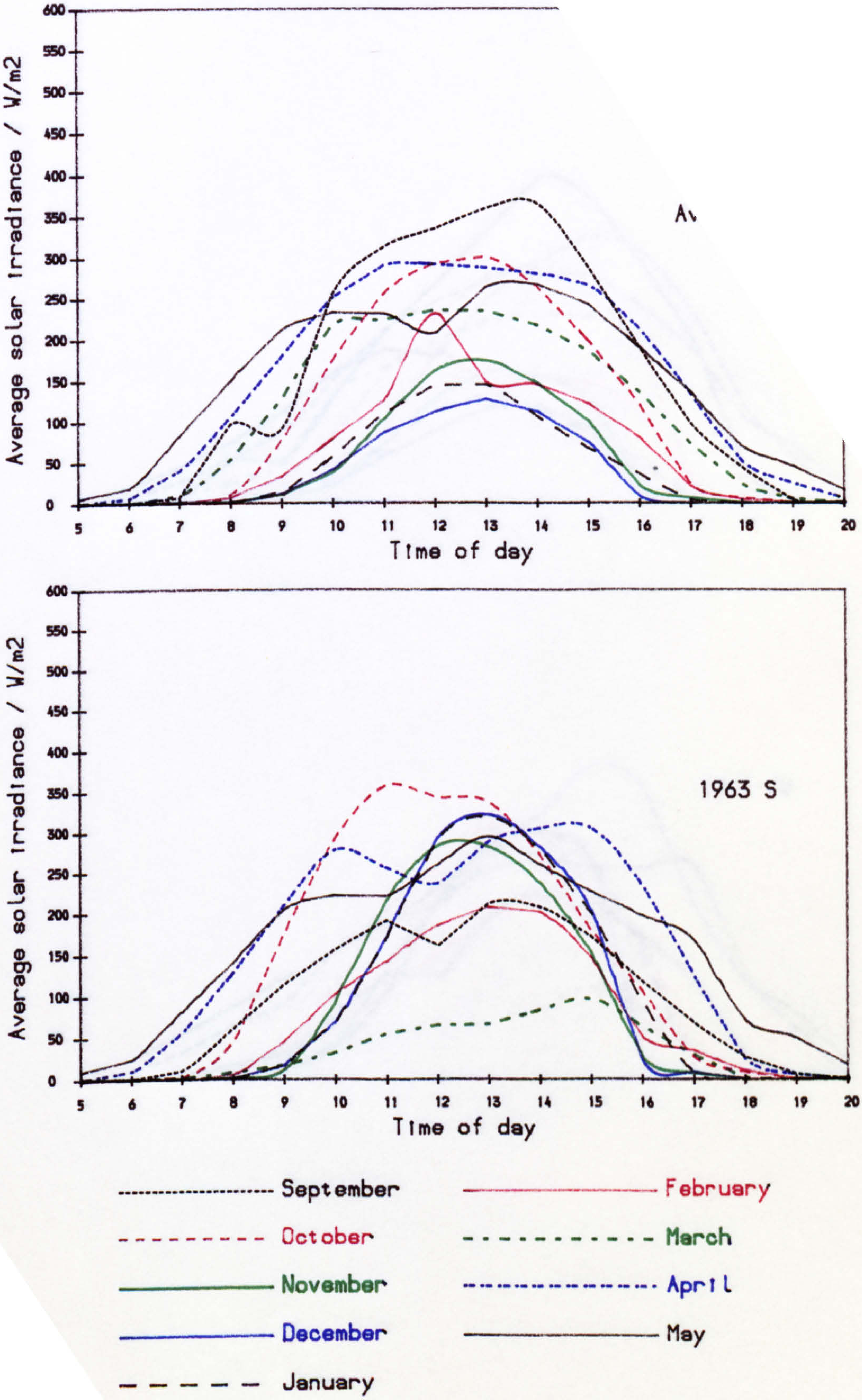


The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Figure (3.6)

Solar Irradiance on a Vertical

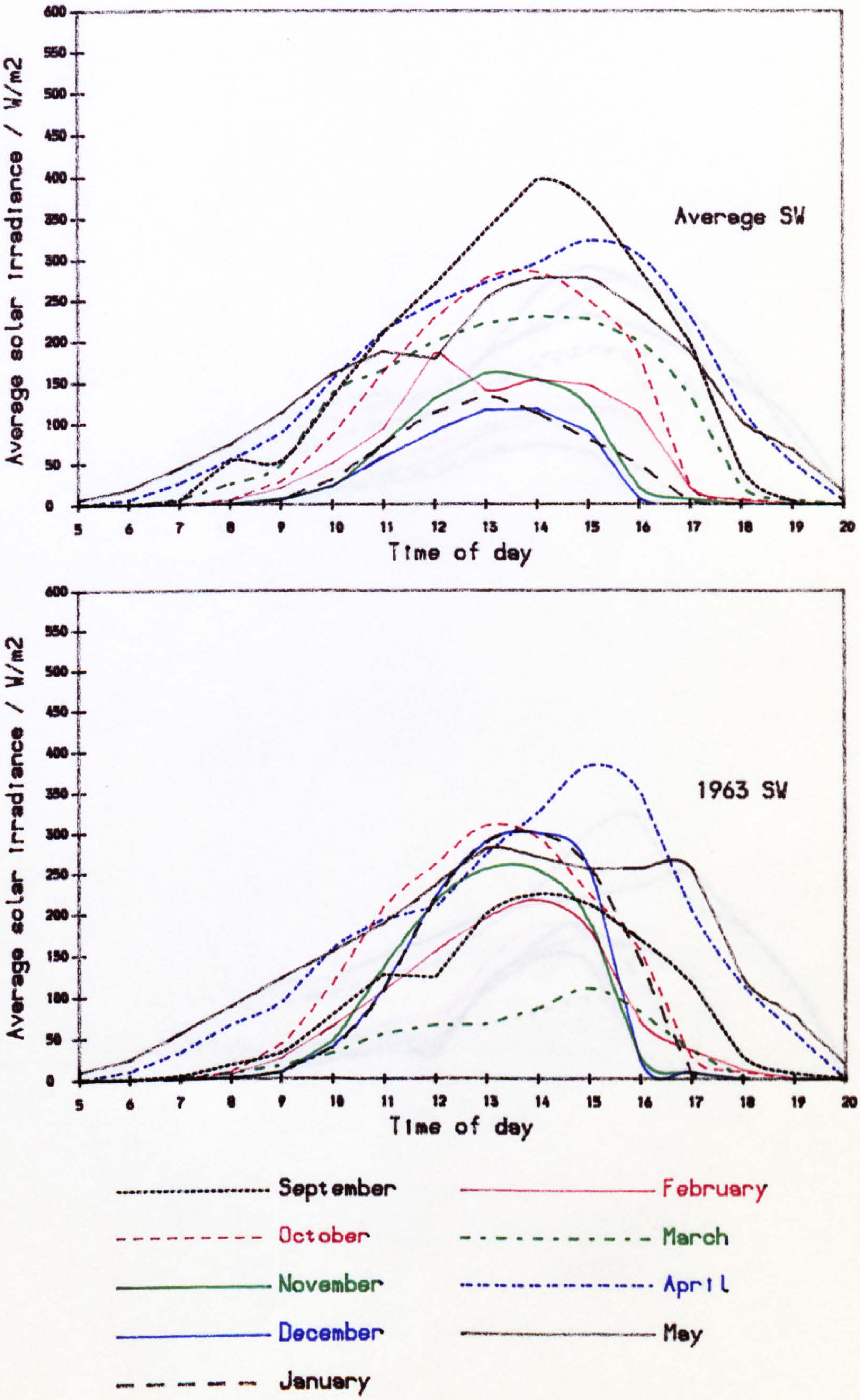


rage is a ten year average from Kew weather data 1959-

from Kew is shown as a typical year

Figure

Solar Irradiance on a Vertical Surface V Time / W/m2

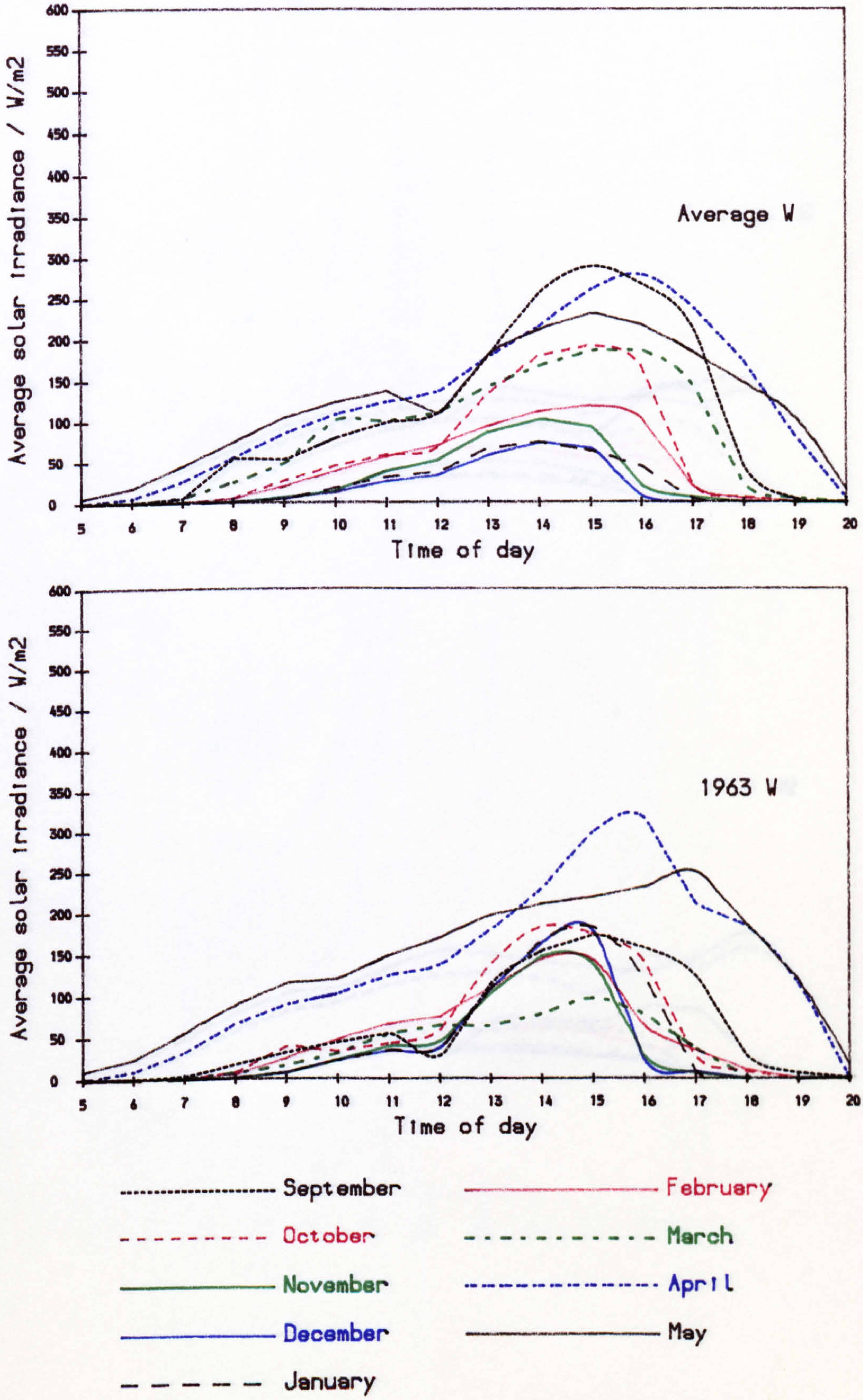


The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Figure (3.8)

Solar Irradiance on a Vertical Surface V Time / W/m2

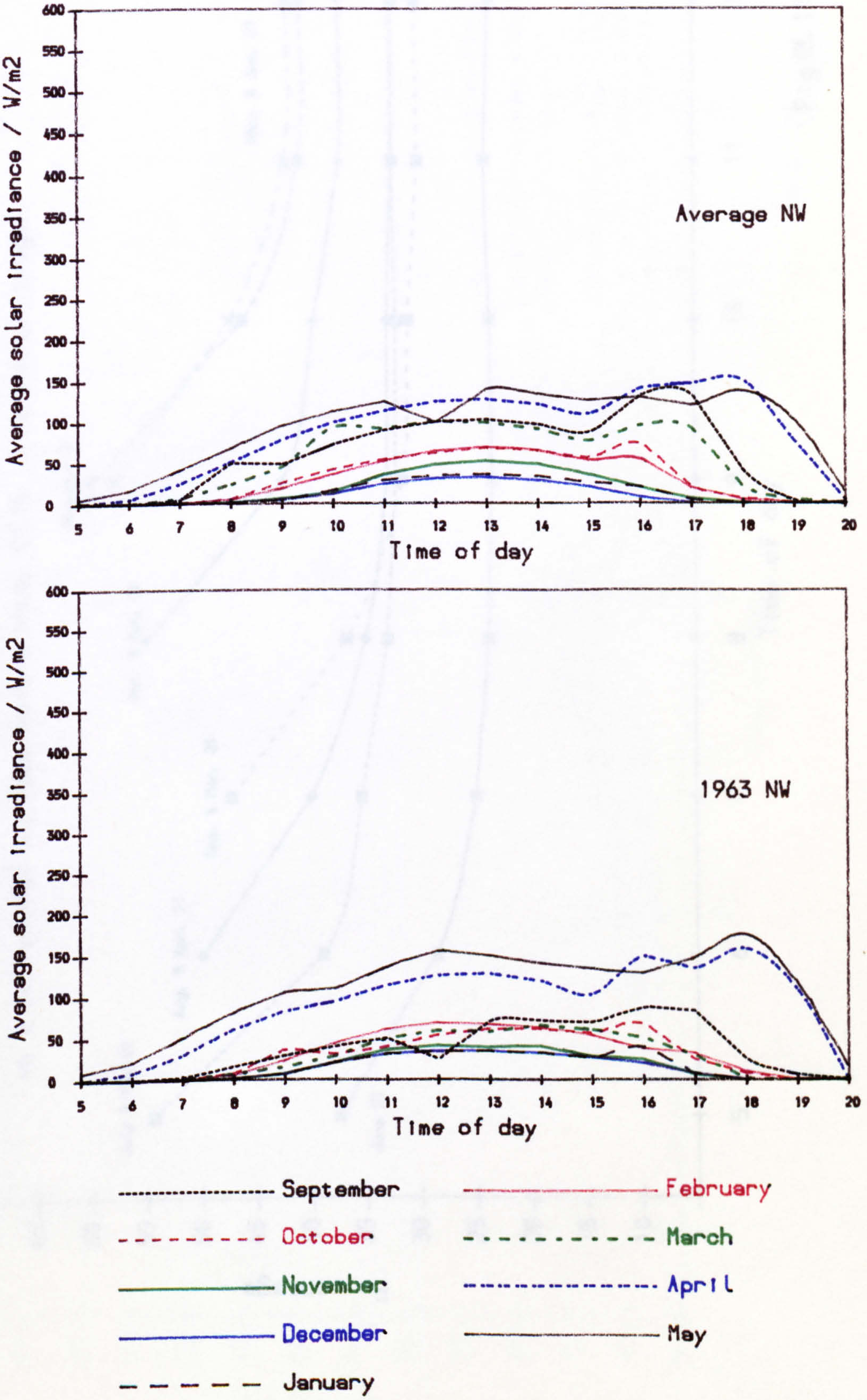


The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Figure (3.9)

Solar Irradiance on a Vertical Surface V Time / W/m2



The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Figure (3.10)

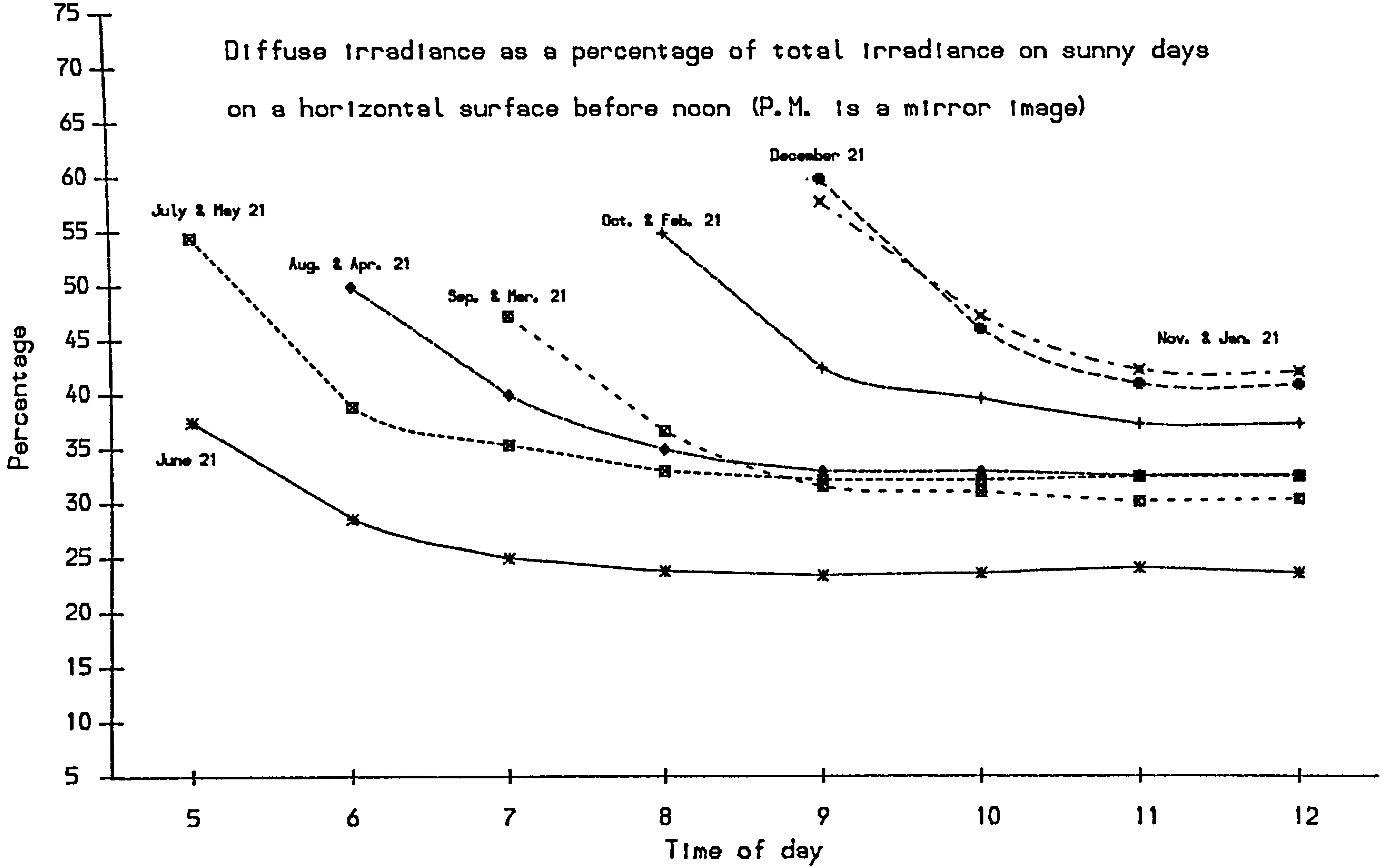
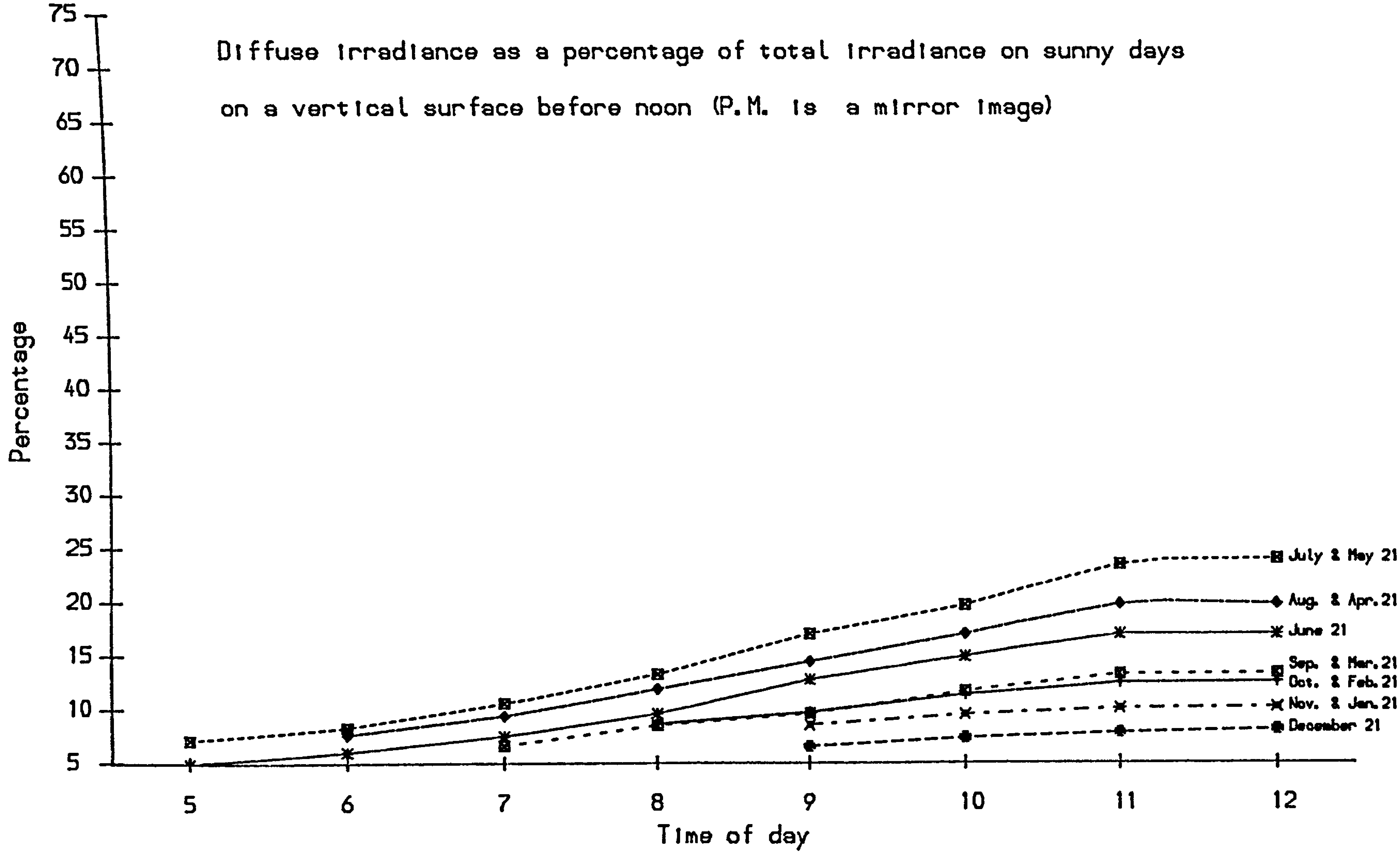

Diffuse irradiance as a percentage of total irradiance on sunny days
on a horizontal surface before noon (P.M. is a mirror image)
December 21
July & May 21
Oct. & Feb. 21
Aug. & Apr. 21
Sep. & Mar. 21
Nov. & Jan. 21
June 21
Percentage
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
5
6
7
8
9
10
11
12
Time of day

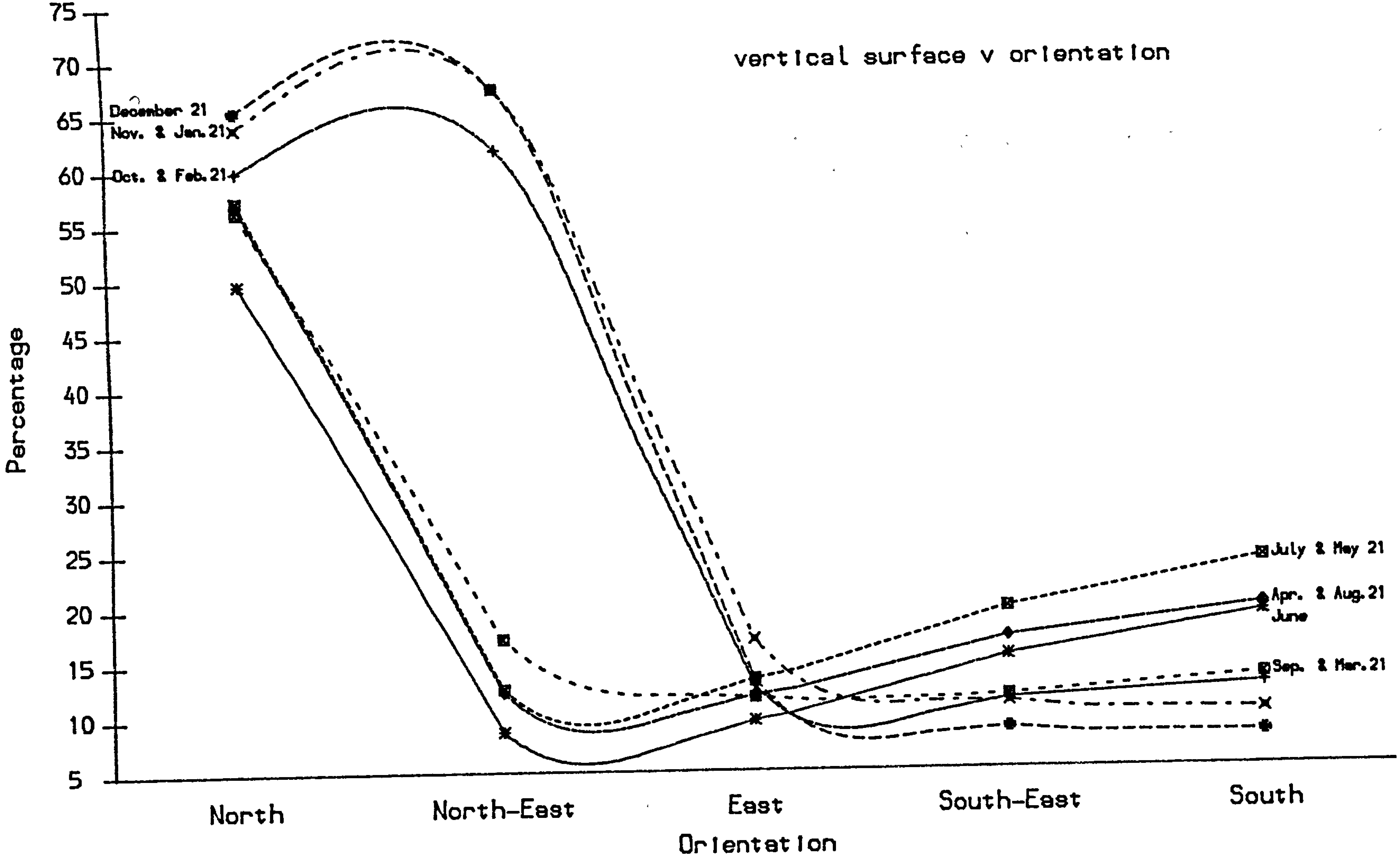
Fig (3.11)


Diffuse irradiance as a percentage of total irradiance on sunny days
on a vertical surface before noon (P.M. is a mirror image)
Percentage
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
5
6
7
8
9
10
11
12
Time of day
July & May 21
Aug. & Apr.21
June 21
Sep. & Mar.21
Oct. & Feb.21
Nov. & Jan.21
December 21

Fig(3.12)

Diffuse Irradiance as a percentage of totalIrradiance on sunny days on a

vertical surface v orientation



Fig(3.13)

Total Irradiances on Opposing Vertical Surfaces v time / W/m2

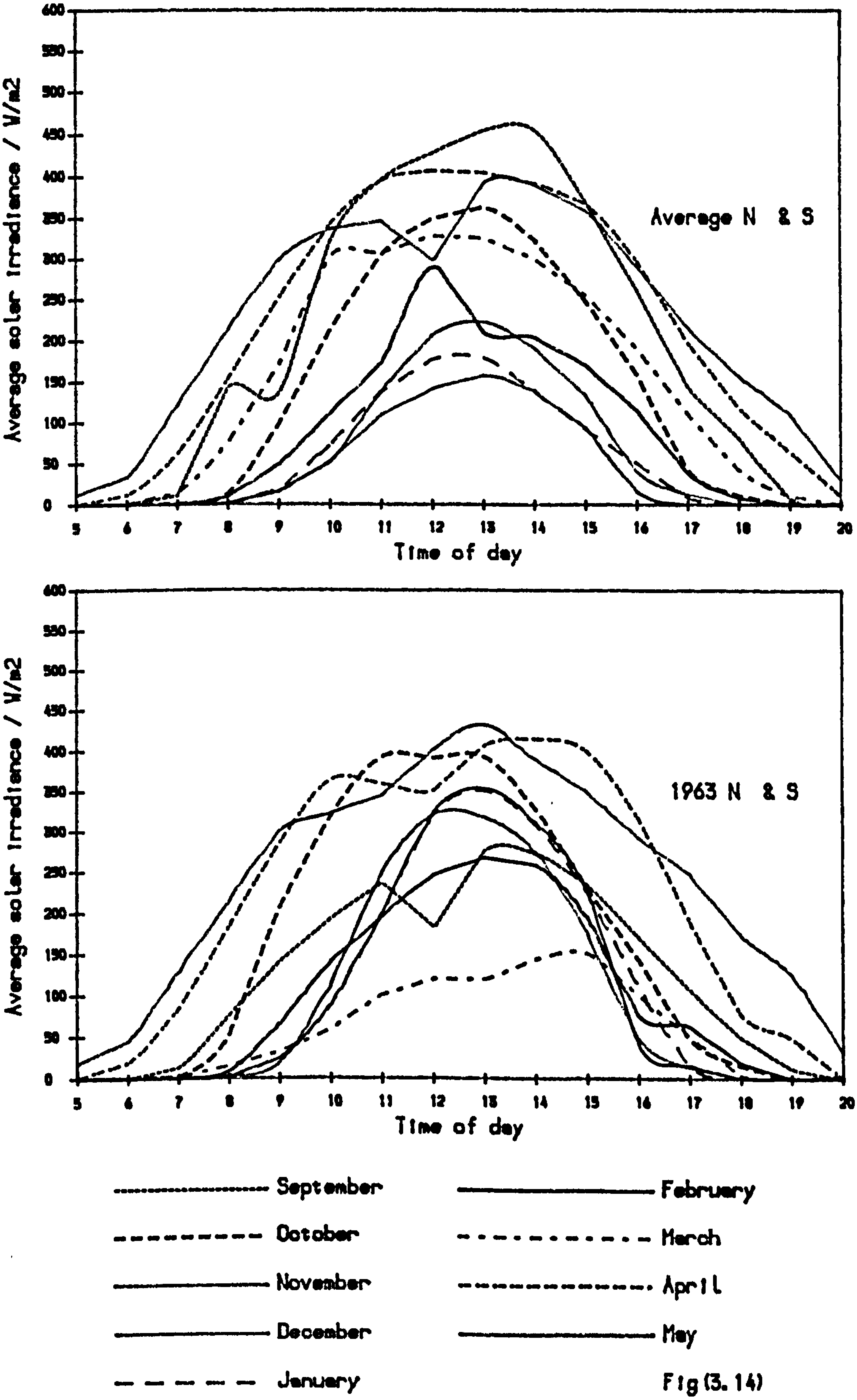


Fig (3.14)

The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Totel Irradiances on Opposing Verticel Surfedes v time / W/m2

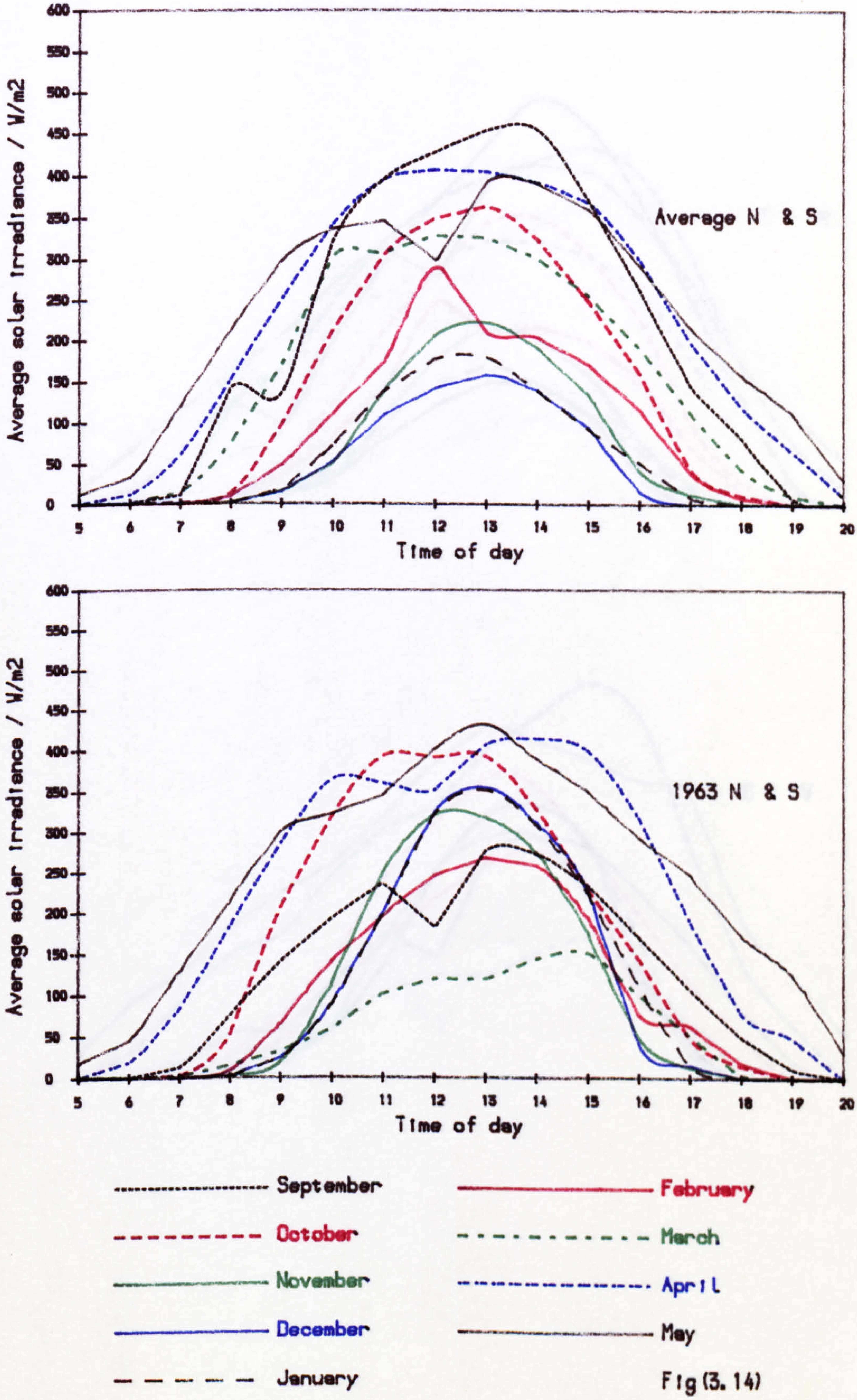


Fig (3.14)

The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Total Irradiences on Opposing Vertical Surfades v time / W/m2

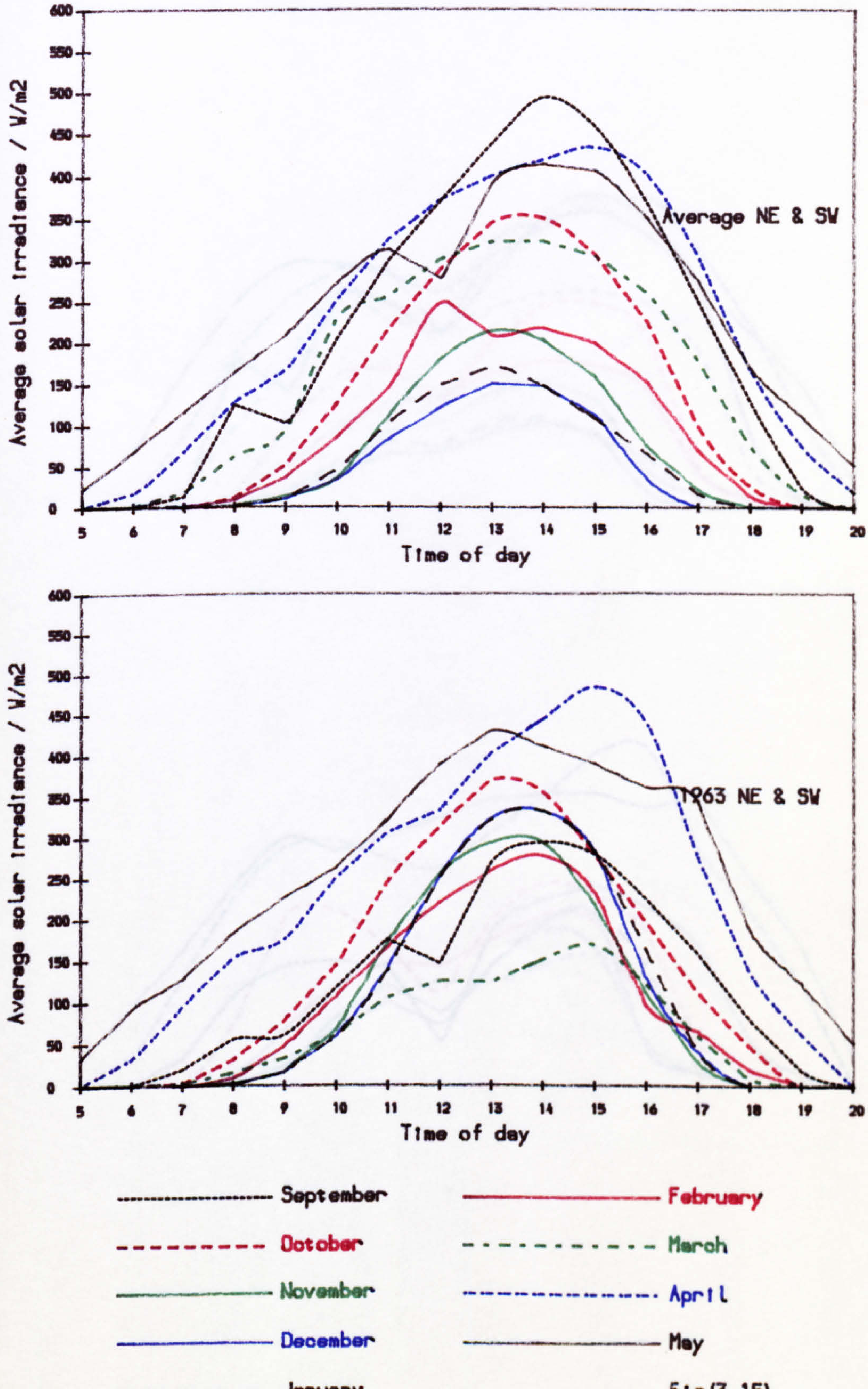


Fig (3. 15)

The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Total Irradiences on Opposing Vertical Surfedes v time / W/m2

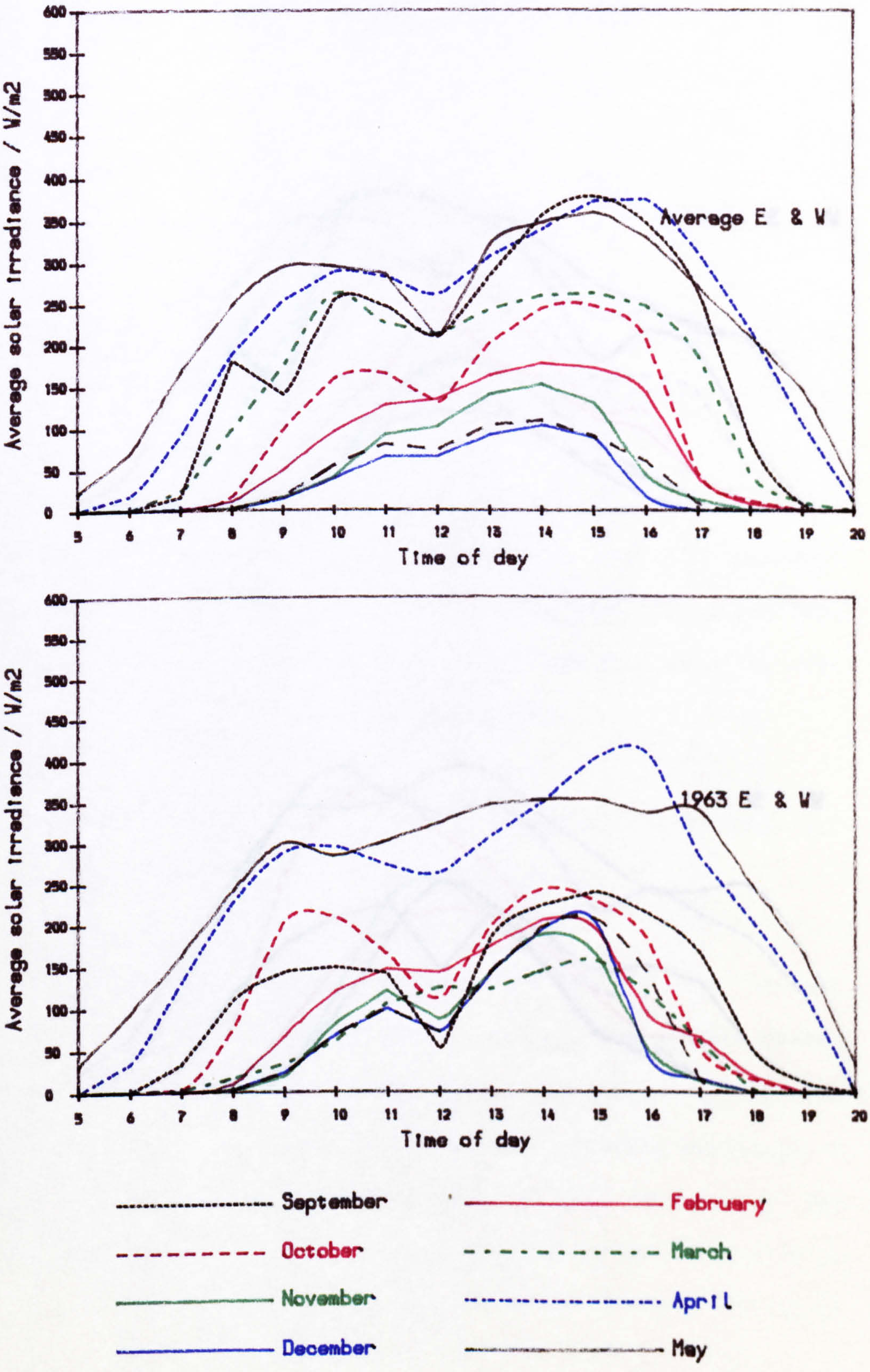
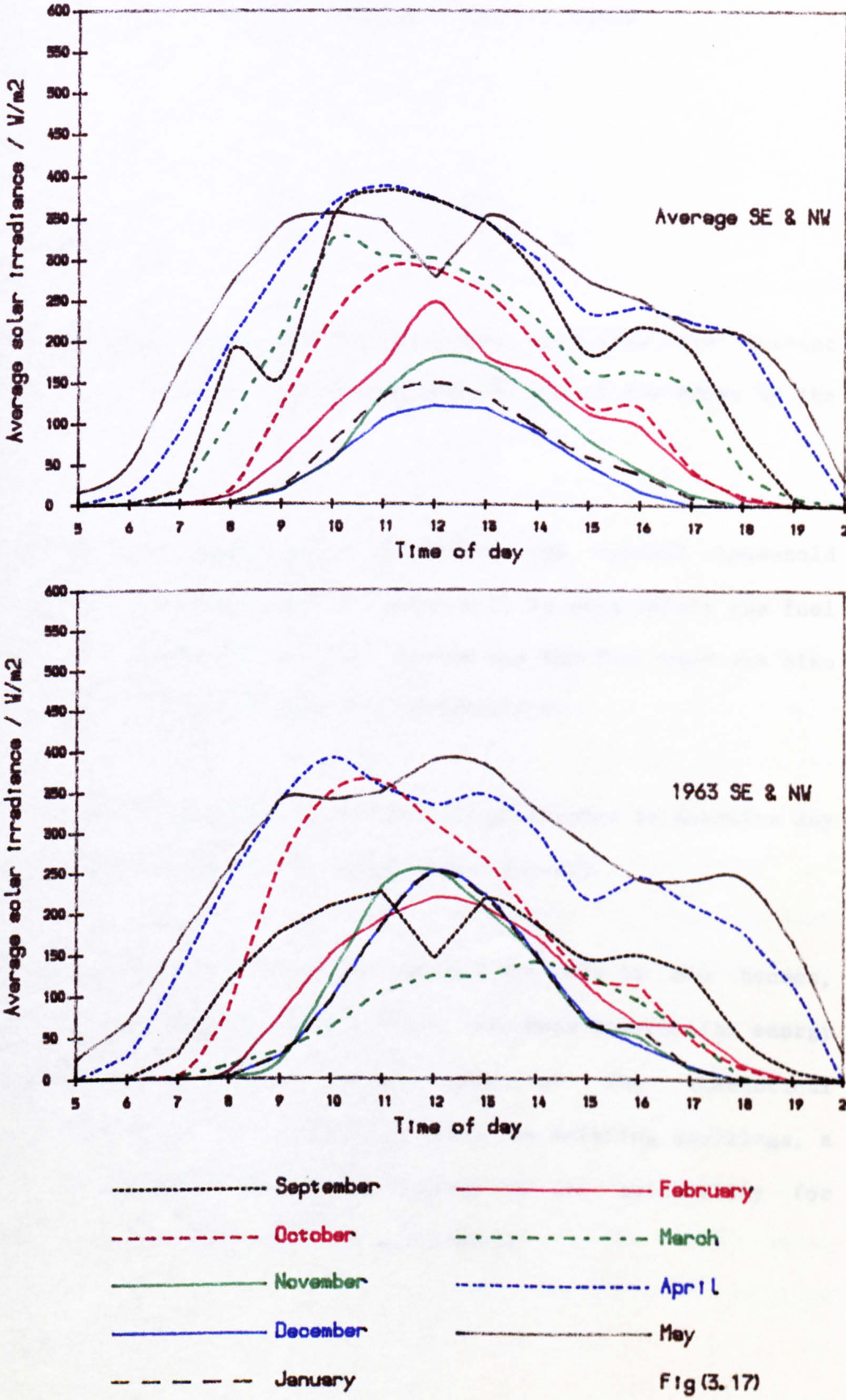


Fig (3.16)

The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

Total Irradiances on Opposing Vertical Surfades v time / W/m2



Fig(3.17)

The average is a ten year average from Kew weather data 1959-68

1963 data from Kew is shown as a typical year

CHAPTER 4 HOUSING, OCCUPANCY AND FUEL USAGE.

4.1 Introduction

A passive solar system, of whatever form, must take into account the nature of the heated environment and the use of the house by its occupants.

The makeup of the household will affect the overall household occupancy and the occupancy pattern, which will in turn affect the fuel consumption. The type of heating system and the fuel used are also likely to have a bearing upon the fuel consumption.

The above criteria will be examined in an attempt to maximise any solar benefits for the individual house and occupants.

The use of the conservatory is confined not only to new houses, it also has a significant contribution to make towards the energy saving in existing dwellings. Since much of the theoretical examination done later is applicable also to existing dwellings, a brief review of the nature of British housing and its suitability for rehabilitative solar systems will be undertaken.

4.2 Housing

4.2.1 Age and Type of Housing

There were about 22 million dwellings in the United Kingdom in 1983. This is a 12 % increase for the ten years up to 1983 (Government Statistical Service,1984) For the country as a whole there has been a fall in the number of houses built in the last few years, the rate of completions in 1982 was little more than half that of 1977. In the public sector, the rate of completions in 1982 is less than a third of those in 1977.

According to the Office of Population Censuses and surveys (1982) there has been a shift in the private sector of England and Wales away from the three bedroom house in favour of smaller and larger houses and an increase in the number of one bedroomed flats constructed, particularly in Yorkshire and Humberside. This trend is typical of most areas, with the exception of the G.L.C. where the trend has been back towards three bedroomed houses. Within the public sector, the growth has been in the building of one bedroomed flats and to a lesser extent, of one and two bedroomed houses.

Despite the low increase in the number of houses built, the increase in the housing stock has been greater than the corresponding increase in population during the period. Hence the ratio of dwellings to population should have increased over the same time.

About half of the houses in Great Britain were built before the beginning of World War II and a third between 1945 and 1970. Table 4.1 shows the age of dwellings at 1972 and at 1982.

Housing is dominated by the semi-detached and terraced house, each representing just over 30 % of housing stock (O.P.C.S.,1982). Table 4.2, a breakdown of the type of housing, for 1981 and Fig (4.1) the combination of house type and age. Detached houses are split evenly through the various age types. Semi-detached houses are typical of between the war and early post war periods. Terraced houses are predominantly, although by no means exclusively, from before 1914.

In addition to any solar system that may be designed for new houses, there is great scope for the rehabilitation of existing houses, the majority of which are not insulated to current Building Standards.

Hawkes and Sousa (1984) laid out two primary criteria for assessing the potential for passive solar heating which were :

a) orientation

b) obstruction.

They conducted a survey of housing in Cambridge which they argue is typical of England. Their criteria for orientation was $\pm 45°$ from south for which 57% of houses complied. Of this 76.5% (33.6% of total) lose less than 20% of the available solar radiation owing to overshadowing. This 33.6% of housing was not evenly distributed across all types of housing. Regarding orientation they concluded:

"In analysing the orientation data by construction date of the dwellings a significant variation was discovered. In summary, this shows that dwellings built between 1919 and 1969 have a more favourable orientation than those built before or since that date."

Hawkes and Sousa's figures are shown in Table 4.3 and show a "consistent correlation" between desirable orientation and periods of low density construction. Because of the low density, the opportunity of constructing houses of a southerly aspect arose more frequently.

4.2.2 Tenure of Housing

There is a trend in the United Kingdom away from rented accommodation. Table 4.4 shows this change for the period 1972-82. Fig (4.2) shows the makeup of housing by age and tenure. It is noticeable that there is very little pre-1914 housing within the local authority sector which is predominantly post war.

Regarding passive solar energy, Hawkes and Sousa claim (1984,p87):

"In response to a question about their attitudes to passive solar heating, only 29.4 % of owner occupiers felt that it would be of no value to them which compared with 64.4 % of tenants in Local Authority housing."

It thus appears that despite the proportion of possible housing suitable for passive solar retrofit within the Local Authority sector there is little desire amongst tenants to have it introduced. A more suitable energy saving system in Local Authority housing may be district heating and/or combined heat and power stations.

Similarly, the private rental sector is unlikely to present any demand for any form of retrofit system other than by enlightened housing associations.

The way ahead for retrofit systems is most likely within the increasing group of owner occupiers.

4.2.3 Household Size

The number of people in a house, their age and the nature of the family give some indication of the heating requirements of the dwelling.

Fig(4.2) shows the household size distribution for the U.K.. The number of households of one or two adults of 16 - 59 years old is a quarter of all households, about 5 million. These are split almost evenly between owner occupier and rented with the emphasis on private rather than public rental. It can be suggested that in households within this group there is less likelihood of finding anyone at home during the day, and the total proportion of rooms in use at any one time may be lower than amongst other groups.

Demographic data suggest that just over a third of all households have one or two people over the age of 60, this is significant since pensioners make up only 17 % of the total population (O.P.C.S.,1983a). It is fair to assume that in the majority of these households, the house is in use for most of the day. It is, however, difficult to estimate what proportion of the rest of the nation's households are in use throughout the day. The best indicator is likely to be that of economic activity. An economically active person is someone who is either working full or part-time, temporarily sick or seeking work. People who are economically inactive include students, the retired and housewives. 69.6 % of households contain one or more economically inactive persons (O.P.C.S.,1982). At least 33 % of households contain children who are regarded as economically inactive but are likely to be at school during the day. This still leaves a minimum of 36% of households with one or more economically inactive adult. The figure is likely to be higher than this because of the number of households in which there is both a child and an economically inactive adult. This gives a possible range of 46 % to 69 % of households with one or more person at home during the day. This corresponds to between 9.2 million and 13.8 million households. Recent trends in unemployment may swell this figure. There is therefore a significant market for solar systems which do not necessitate heat storage.

4.3 House Usage

4.3.1 Household Occupancy

The household size is likely to affect the pattern of occupancy of the house and the number of rooms used. A couple in a house are likely to use one or possibly two rooms at any one time whereas a large family may be using every room. The size of the family is likely to determine the house use and hence the energy demand. The makeup of the household may also determine the internal air temperature.

The household size is related to the size of the house. A 1969 study of a Local Authority housing estate in Sheffield (Ministry of Housing and Local Government,1969) examined the occupancy of 2, 3 and 4 bedroomed dwellings. The two bedroomed dwellings were intended for 4 people, the three bedroomed for 5 and the four bedroomed for 6. The report concluded that 24 % were correctly occupied according to the design, 15 % were overoccupied, in particular the larger houses, and 61 % under occupied. It must be noted that Sheffield City Council's policy at the time was to try to offer the tenants the kind of dwelling that they wished.

Government Figures (O.P.C.S,1983b, Table 5.25) for the difference from the Bedroom Standard are shown in Table 4.5. The bedroom standard allocates one room for a married couple, one bedroom for children under ten and one bedroom for children of similar sex over 10 and one room for each additional adult. Children of similar sex above and below the age of ten are expected to share.

For outright owner occupiers, that is owner occupiers without a mortgage, 81 % of households exceed the bedroom standard by one or more room and for owner occupiers with mortgages the figure is 70%.

Under occupancy is less common in the rented sector, the number of dwellings that equal the standard being significant in all sections other than those rented with a job. Within the public sector there are still a large number of households that are under occupied.

Considering all forms of occupancy, there are about 12.3 million households in the country that are underoccupied. Those households that heat the whole house are likely to be using more fuel than their occupancy would suggest.

This being the case there is good reason to provide a cheap form of background heating for the whole house rather than heat it all to comfort levels. Only the rooms that are heavily used could be heated fully. Solar systems are particularly suitable to the provision of all or part of this background heating since the heat that they generally provide is of low grade. Suitable storage such as a concrete upper floor may dissipate sufficient heat to warm the unused rooms sufficiently without need for additional heating, ensuring that the house never becomes too cold. When the room is likely to be needed, normal heating could be switched on. The concrete floor's storage will be examined (Chap 8) and several houses are to be built with a first floor concrete store (Chap 9)

The trend towards overoccupancy may be changing. As mentioned above (Section 4.2.1) there is a move towards the construction of smaller and larger private houses and one bedroomed private flats. Additionally the public sector is building more one bedroomed houses and flats.

4.3.2 Room Heating and Usage

Poon's (1985) research into the occupancy and fuel usage of a sample of houses in Wakefield showed that there was a wide range of hours occupied for each room. His results are shown in Table 4.6. The first bedroom is occupied less than the other two since it was normally occupied by adults, whereas the other bedrooms tended to be occupied by children, who sleep longer.

Poon determined that the nature of the heating system did not affect the use of the total dwelling but may affect the occupancy of certain rooms, in particular the living room.

The occupancy pattern affects the use of rooms, although for rooms that are used predominantly in the evening there is no change. The only room for which Poon found a marked increase in usage with a full occupancy was the living room which was used for three hours longer per day in houses with full day occupancy. The time of use of the kitchen varied with occupancy but the total number of hours of use remained similar.

The number of hours rooms were heated varied, with the living room being heated the longest. The third bedroom was heated for longer periods than the other bedrooms. Poon also found that the living room was generally heated for longer periods than it was occupied. The same is true of the kitchen although the incidence of the reverse is greater for kitchens than for living rooms. The bedrooms were heated for less time than they were used.

4.3.3 Orientation of Rooms

As was shown in the previous chapter, the common method of orienting houses on an east-west axis is the most desirable for most factors.

The use of rooms suggests specific orientations are more suitable than others for particular rooms. This is not only because of the amount of use of the room but also the time of greatest use.

Since the living room is heated longest and generally to the highest temperature it makes sense for this room to benefit the most from any form of direct solar gain, particularly since it is generally heated longer than it is used. This suggests that the room should be oriented so that it receives the maximum sunshine. However for houses that are intermittently occupied, this could mean that the room was warmed when not occupied. Additionally it is not generally possible to determine the occupancy at the planning stage. It has been shown that irradiance is greater in the afternoon than the morning, therefore it is suggested that living rooms should desirably be oriented west of south, thus prewarming the room for the evening, its time of peak use.

Work by Bonchair (1986) has shown that in the U.K. south-west orientation is greater for solar gain because of the outside air temperature change during the day.

Tenants in Sheffield remarked (Ministry of Housing and Local Government, 1969) that they considered it desirable to receive afternoon sunshine in the living room.

The kitchen may also benefit greatly from solar gain. Since it is the room that is more likely to be used in the morning its orientation to the east or south-east will be beneficial. Orienting it to the west is likely to be just as useful but the kitchen may be the only room downstairs that can benefit from the morning sun.

Bedrooms two and three may often be used in the evening as additional living rooms or studies. They would therefore benefit from facing west. Bedroom one is commonly used only for sleeping therefore there is little to be gained by facing it west. However an easterly first bedroom is useful not only for the desirability of getting the morning sun but the occupants are likely to benefit from direct gain at the beginning and end of the heating season when the sun rises before or at about the time of getting up and the outside air temperature is relatively low.

Since it is regarded desirable for all rooms to receive sunshine at some time, all rooms should have a window facing between 50° and 310°

bearing from the north.

The halls and landing are used briefly and may often be kept at a lower temperature, it is therefore best to have them on the north of the house.

4.3.4 Room Temperatures

The first legal note of desirable temperatures is in The Factories and Workshop Act of 1901 (Statutes,1901) which requires that thermometers should be placed at convenient locations and that the temperature should be regularly monitored. From 1937 the Act (Statutes,1937) required that a minimum air temperature of 60 $^{\circ}$F (15.6 $^{\circ}$C) should be maintained from one hour after the start of work. The rule is similar for The Offices, Shops and Railway Premises Act (Statutes,1963). There has been no change in the recommended temperature except to round it to 16°C folowing metrication.

Desirable room temperatures are higher for the home. Most central heating systems are designed to maintain the house at a steady 20-21°C. There is however no need to maintain the whole house at the same temperature since the desirable temperature is dependent upon activity which varies from room to room. Bedrooms with very low temperatures can be comfortable for sleeping providing that the bedclothes are adequate. This makes the room uncomfortable for getting in and out of bed and unsuitable if the bedroom is to be used for other activities. Bedrooms, if used during the day and evening, should be considered as similar to living roms where the activity is generally sedentary. In the kitchen the activity is higher unless it is used for eating. Bathrooms are similar to kitchens except that the level of clothing is low. In halls the activity level is moderate to high.

Humphrey (1976) suggests that the normal day temperature (TAI) for a dwelling should be 19^{o}C with the provision to raise or lower the temperature by 4 K, hence about 21^{o} C for living rooms, 17 ^{o}C for kitchens, 15^{o} C for halls and bedrooms for sleeping and 22^{o}C for bedrooms used as studies or sitting rooms. It is unclear from Humphreys' work why the bedroom used as a sitting room should be 1 K higher than the living room. Table 4.7 compares Humphrey's recomendations with those of the C.I.B.S.E.(1970) The recommendations are very similar with the exception of those for the bathroom.

The actual recorded temperatures in houses may vary considerably from these recommendations. Apart from the fact that ideas of thermal comfort may vary considerably, the nature of the family, the type of housing, their economic circumstances, the heating system and the type of fuel used may all affect the internal temperatures.

Hunt and Gidman (1982) conducted a survey of dry bulb house temperatures in 1000 houses nationwide. The results are shown in Table 4.8. The mean dwelling temperature was found to be 15.8^{o}C with the downstairs some 2 K warmer than the upstairs. They noted that the mean temperatures of the downstairs rooms, with the exception of a third reception room (which was rare), were always higher than the mean of any of the upstairs rooms. However with the exception of the landing, the mean of the recordings were all lower than those recommended by the C.I.B.S.E. .

Additionally Weston (1951) showed that internal temperatures were not constant, but instead fall with decreasing outside temperature at the rate of about 0.5 ^{O}F for every 1^{O}F drop outside. His research, conducted at Abbots Langley from May 1948 to May 1958, was on houses of a standard of insulation which would be considered low today. The effect was least marked in the living room for which the rate is 0.4^{O}F /F for the weekly mean and 0.25^{O}F/^{O}F for the evening.

4.4 Fuel Usage

4.4.1 Central or local heating

Table 4.9 shows the increase in the number of houses with central heating of some form. It has increased from 35 % to 58 % in ten years. Central heating is not evenly spread amongst all household types. Tables 4.10 and 4.11 show the distribution of central heating by tenure and accommodation. Over half of all owner occupiers have central heating with those houses that have mortgages making up the highest proportion. Around half of the houses in the public sector and housing associations have central heating but few privately rented dwellings are centrally heated. The most common types of house to be centrally heated are detached and semi-detached.

The main type of fuel for heating is gas (Table 4.12) with 70 %

of centrally heated dwellings using it. For locally heated dwellings the dominance by gas is less extreme but it is still used in over half of them.

Hunt and Gidman (1982) showed that overall house temperatures are generally 3 K higher in centrally heated dwellings. The temperature difference was more marked upstairs. The upstairs was 3.7 K warmer compared to the downstairs which was 2.4 K warmer. In addition the mean upstairs temperature in centrally heated dwellings was significantly higher than the mean downstairs temperature in locally heated dwellings. Far more use can therefore be made of the centrally heated dwelling during the heating season with the whole house being available for many activities, whilst in locally heated dwellings many of the rooms will be unheated and hence unusable. However in centrally heated dwellings, much fuel may be being used in heating rooms in underoccupied houses to 20°C.

Poon (1985) showed that the type of fuel used also had an affect on the use of central heating, especially if solid fuel is used. Solid fuel centrally heated houses had their heating on for much longer periods that those with gas because of the longer warm up period. The occupants often left the heating on all the time at a low background level.

Comparing the ratio of occupancy to heating, non centrally heated houses during the heating season were occupied 1.5 to 2 times longer than they were heated. For gas centrally heated dwellings the ratio was close to unity but solid fuel centrally heated dwellings tended to be heated three times longer than occupied.

A means of reducing the overall fuel demand whilst maintaining the benefits of central heating would be to provide some form of centrally generated background heating to maintain the whole house at 12 - 15°C and additional means of local heating in each room. The source of background heating opens many approaches for use of low grade heat including passive or active solar systems and district heating.

4.4.2 Fuel Pricing and Household Income

The price of fuel supplied to the household is likely to determine the economic viability of any energy saving measures that may be considered by the householder by virtue of the likely pay back period. In addition the price of fuel may determine its use.

Weston's (1951) analysis of heating in occupied houses was initially undertaken with the occupants receiving a subsidy equal to two-thirds of their fuel bill. The following year, this was reduced to one third and in the final year the subsidy was removed completely. There was therefore a threefold increase in the occupants fuel prices over three heating seasons. Despite this, expenditure over the final heating season was only double that of the first year thus showing a reduction in fuel input allied to price increase. Occupants were either willing to put up with lower temperatures or were forced to do so by limits on their expenditure.

The overall expenditure on fuel, power and light as a proportion of the total expenditure has remained fairly static over the last twenty five to thirty years at between 5% and 7% (Department of Employment,1957-1983), the lowest level of 5.1% was in 1974.

The proportion spent on fuel, power and light does not remain constant with variation of earnings. Fig (4.3) shows the expenditure on fuel for various earnings groups. The figures only go up to£500 per week since they become unreliable above this.

The amount spent on fuel increases with earnings but not proportionally. The proportion spent on fuel decreases sharply with increases in weekly wage in the lower earnings sector suggesting that at the bottom of the "earnings league" people are spending less on fuel than they consider desirable. The proportion spent on fuel continues to decrease above the average household income of£187 per week.

4.5 Occupancy Patterns

It is generally assumed that household occupancy is either continuous or intermittent, intermitent usually being morning and evening occupancy.

Even in a house that is considered to have continuous occupancy there are likely to be periods during the day when the house is unoccupied for one or two hours such as described in the study of Sheffield housing (Ministry of Housing and Local Government,1969)

Whether the house is heated during this time will depend upon many things including the heating system and the type of fuel used. Additionally, the heating may not be left on during the whole of the day despite full occupancy.

An intermittently occupied house may have great variation in the period of occupancy and necessarily of heating regime.

4.5.1 Occupancy and Fuel Consumption

To analyse the effect of time of occupancy upon the fuel consumption of the household, the Kew weather data from 1959 to 1968 described in Chapter 3 were examined.

A value for "degree hour" was calculated where the degree hour was the number of hours below which the temperature was 15.5°C multiplied by the difference from 15.5°C. It is an hourly equivalent of the degree day. The degree day was calculated from the average daily temperature. The results are summarised in Table 4.14 for the hourly values over the ten year period with the standard deviation for each hour and the average value for degree day.

The overall value of 1971 degree days compares with the value of 2012 given in the C.I.B.S.E. guide for the Thames valley. The C.I.B.S.E. guide is based on data from the Gas Board over twenty years from 1951 to 1971. The difference between the two values is about 2 %. Fig (4.5) shows these results and compares them with the daily average degree day. Between 10.00 h and 21.00 h the values are beneath the average. Table 4.15 shows a summary of the total degree days for various occupancies. In each case, the heating is assumed to be on one hour earlier than the corresponding heating period, hence the degree hours from the preceeding hour is added to the sum. Dividing the total by 24 gives a value for the degree day for that regime.

A more realistic value for full time heating is given by considering a heating period between 6.00 h and 24.00 h. This will make a sizeable difference since as can be seen from Fig (4.5) 0.00 h to 6.00 h is a period of above average values. The overall difference is between 22 % and 26 %.

Values for overall degree days have been calculated for different periods of intermittent occupancy for the morning and evening. The later the period of morning occupancy after 6.00 h, the lower the morning value will be. The inverse is true for the evening. The range for the suggested intermittent regimes is 733 - 975 degree days which is about half to two-thirds of the value for full occupancy.

These values are not precise since they do not take into account many factors such as the type of house or heating system and they assume a massless building, but they give an indication of the variation of fuel consumption with occupancy and time of occupancy. A More sophisticated approach would be the use of the admittance method or the Response Factor method to examine the effect of the building dynamics. The reader is refered to A5 of the CIBSE guide. (CIBSE, 1981)

4.6 Summary and Conclusions

4.6.1 Much of Britain's housing is old. About one third of it is suitable for passive solar retrofit according to the criteria of orientation and obsruction. Housing built between 1919 and 1969 is the most suitable

4.6.2 There has been a steady increase in the number of owner occupiers and it is owner occupiers who are likely to be the most amenable to any form of passive retrofit.

4.6.3 At least half of the households have somebody at home during the day, there is hence a large market for simple direct gain solar systems that do not require storage.

4.6.4 Houses tend to be underoccupied, particularly within the private sector but there is a trend towards the construction of smaller houses.

4.6.5 The nature of the household determines the occupancy and heating patterns. The living room and kitchen tend to be heated longer than occupied but all rooms are at a lower temperature than the standards suggest. Room temperatures vary with outside air temperature. A solar system may reduce this variation, reduce the energy consumption for rooms that are heated longer than used and make the remaining rooms more useable.

4.6.6 For the purpose of direct gain and the time of use of the rooms, the living room should face south-west, the kitchen east, bedroom 1 east, other bedrooms west and the hall and landing north.

4.6.7 Central heating produces higher temperatures but may result in unused rooms being heated to a high level for periods of little use. Some form of low grade background heat and efficient local heating may have the same effect.

4.6.8 The price of fuel alters fuel usage particularly amongst low earners. Many people are not heating their house sufficiently. Any form of "free energy" would improve comfort conditions rather than reduce consumption for many people.

4.6.9 The time of occupancy affects fuel consumption. Intermittently occupied houses may use about half of the fuel of those with full occupancy hence any reduction in consumption of fully occupied houses during the day may have substantial savings.

Table 4.1 AGE OF DWELLINGS

@ December 1972 %

Date of construction	Pre 1891	1891-1914	1919-1939	Post 1944
U.K.	34		17	49
England	19	15	24	42
Wales	26	20	16	38

@ December 1982 %

Date of construction	Pre 1891	1891-1914	1919-1939	1945-1970	Post 1970
U.K.	16	14	21	34	15
England	16	13	22	34	15
Wales	23	18	14	31	14

Regional Trends 1984, Government Statistical Office

Table 4.2 TYPE OF ACCOMODATION (1982)

Detached	17%
Semi-detached	31%
Terraced	32%
Purpose built flat or maisonette	14%
Converted flat of maisonette	5%
Business / other	1%

General Household Survey 1982

Table 4.3 FAVOURABLE ORIENTATION BY AGE OF DWELLING

Date of construction	% of dwellings with favourable orientation	density / dwellings per acre
Pre 1900	45	72.9
1900-1914	47	61.8
1919-1939	64	29.1
1945-1963	70	37.9
1964-1969	68	53.7
Post 1969	54	60.0

Hawkes & Sousa.

Table 4.4 Tenure of Dwellings in the U.K. %

Owner Occupied			Rented from Local Authority or New Town			Rented from Private Sector or Housing Association		
72	77	82	72	77	82	72	77	82
51%	54%	59%	31%	32%	29%	18%	14%	12%

Regional Trends 1984

Table 4.5 DIFFERENCE FROM BEDROOM STANDARD BY TENURE (GREAT BRITAIN 1982)

Difference from bedroom standard (bedrooms)	Tenure: Owner occupied: Outright	Owner occupied: Mortgage	Rented: with job	Rented: Local Auth.	Rented: Housing Assoc.	Rented: Unfurnished private	Rented: Furnished private	Total
1 or more below std	2	4	6	7	6	4	14	5
Equals Standard	15	27	29	43	62	32	62	31
1 above std	43	43	40	36	26	39	16	39
2 or more above std	40	26	26	15	7	24	8	25
% of houses	23	31	2	34	2	6	2	100

Table 4.6 NUMBER OF HOURS ROOMS ARE OCCUPIED

Room	Mean hours occupied	Standard error
Living room	9.6	0.3
Kitchen	4.8	0.3
1st bedroom	8.6	0.1
2nd bedrrom	9.7	0.3
3rd bedrrom	9.3	0.4

Poon 1985

Table 4.7 RECOMMENDED ROOM TEMPERATURES

Room	Humphrey °C	C.I.B.S.E. °C
Living room	21	21
Kitchen	17	--
Bathroom	19	22
Bedroom (sleeping)	15	18
Bedroom (other)	22	21
Halls	15	16

Humphrey 1972, C.I.B.S. Guide 1970

Table 4.8 Survey of House Temperatures

Room, space	no. of rooms	no. of readings	mean/^{o}C	Standard Dev./^{o}C
Living room	901	891	18.[illegible]	3.0
Reception 2	427	398	16.3	3.3
Reception 3	51	46	14.7	4.2
Kitchen	881	844	16.7	3.1
Hall	804	763	15.6	3.2
Landing/stairs	592	560	15.4	3.2
Bathroom	850	773	15.1	3.3
Bedroom 1	884	816	15.2	3.3
Bedroom 2	801	729	14.4	3.3
Bedroom 3	537	480	14.1	3.4
Bedroom 4	85	69	14.6	3.7
Bedroom mean		816	14.6	3.3
Upstairs mean		900	16.8	2.8
Downstairs mean		837	14.8	3.2
House mean		900	15.8	2.9

Hunt & Gidman 1982

Table 4.9 Percentage of Houses with Central Heating 1971-1981

1971	1973	1975	1977	1979	1980	1981	1982
35%	40%	47%	51%	54%	56%	58%	59%

General Household Survey (1981 & 1982)

Table 4.10 Percentage of households with central heating by tenure

TENURE

Owner Occupied		Rented					Total
outright	mortg.	with job	Local Auth.	Housing Ass.	Unfurnished private	furnished private	
61%	77%	52%	49%	64%	23%	31%	60%

General Household Survey (1982)

Table 4.11 Proportion of Households by Type of Accomodation with C.H

Detached	Semi-detached	Terraced	Purpose-flat	Convt.flat	Buisness
83%	63%	47%	58%	36%	45%

Table 4.12 Main Type of Fuel used for Room Heating in Winter

	Solid Fuel	Electricity	Gas/ Calor	Oil/ Parrafin	other
C.H.	11%	12%	70%	7%	-
non C.H.	26%	21%	58%	3%	4%

General Household Survey 1982

Table 4.13 Degree Hour Data from Kew 1959-1968

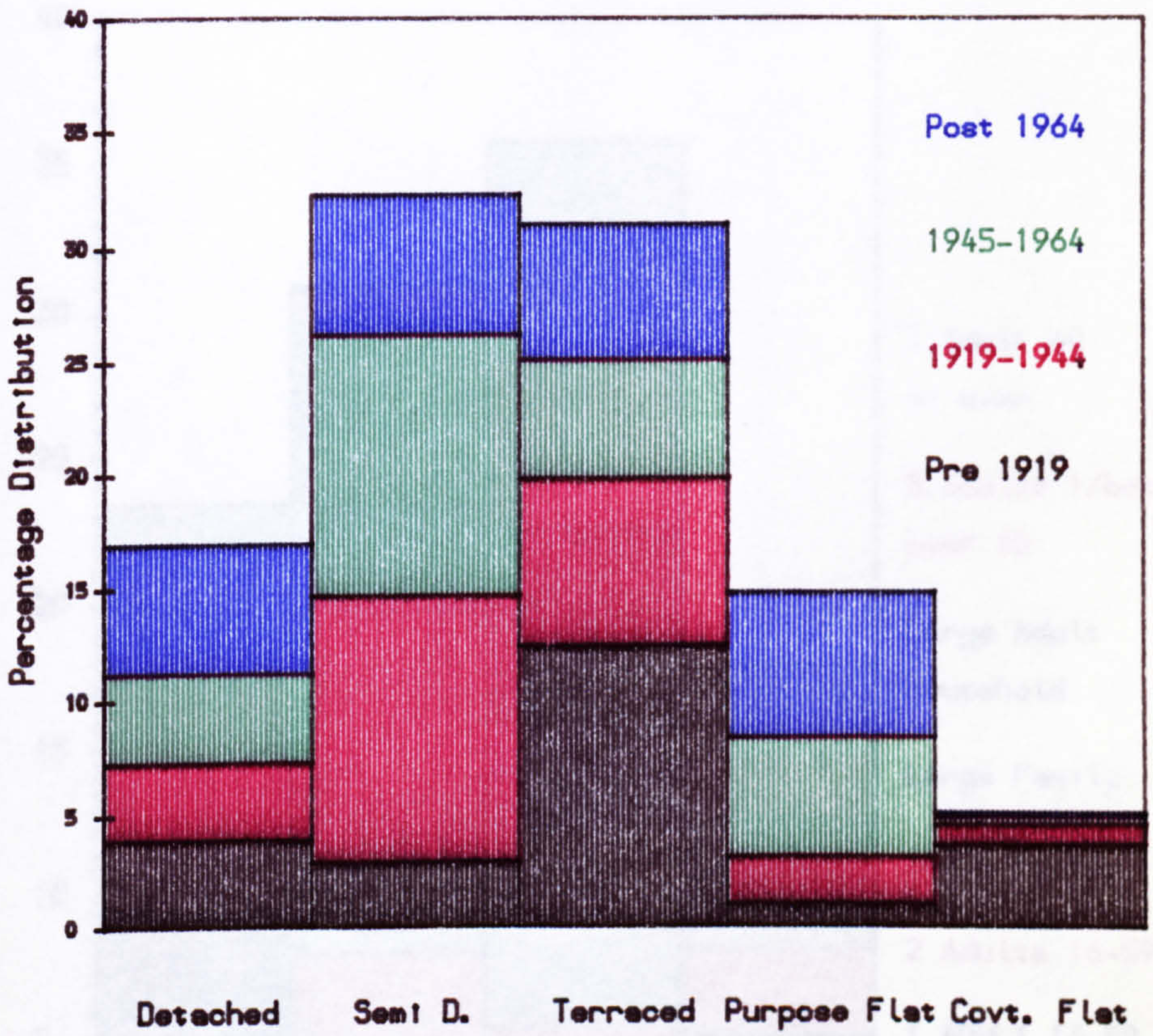
Time	Degree hour	Standard Deviation
0 - 1	2354	176
1 - 2	2441	174
2 - 3	2515	177
3 - 4	2578	172
4 - 5	2631	172
5 - 6	2633	175
6 - 7	2565	181
7 - 8	2446	179
8 - 9	2267	174
9 - 10	2065	174
10 - 11	1873	163
11 - 12	1704	159
12 - 13	1580	162
13 - 14	1498	160
14 - 15	1460	156
15 - 16	1464	157
16 - 17	1522	159
17 - 18	1606	161
18 - 19	1704	168
19 - 20	1822	172
20 - 21	1942	175
21 - 22	2051	179
22 - 23	2163	180
23 - 24	2258	179
Degree day	1971	171

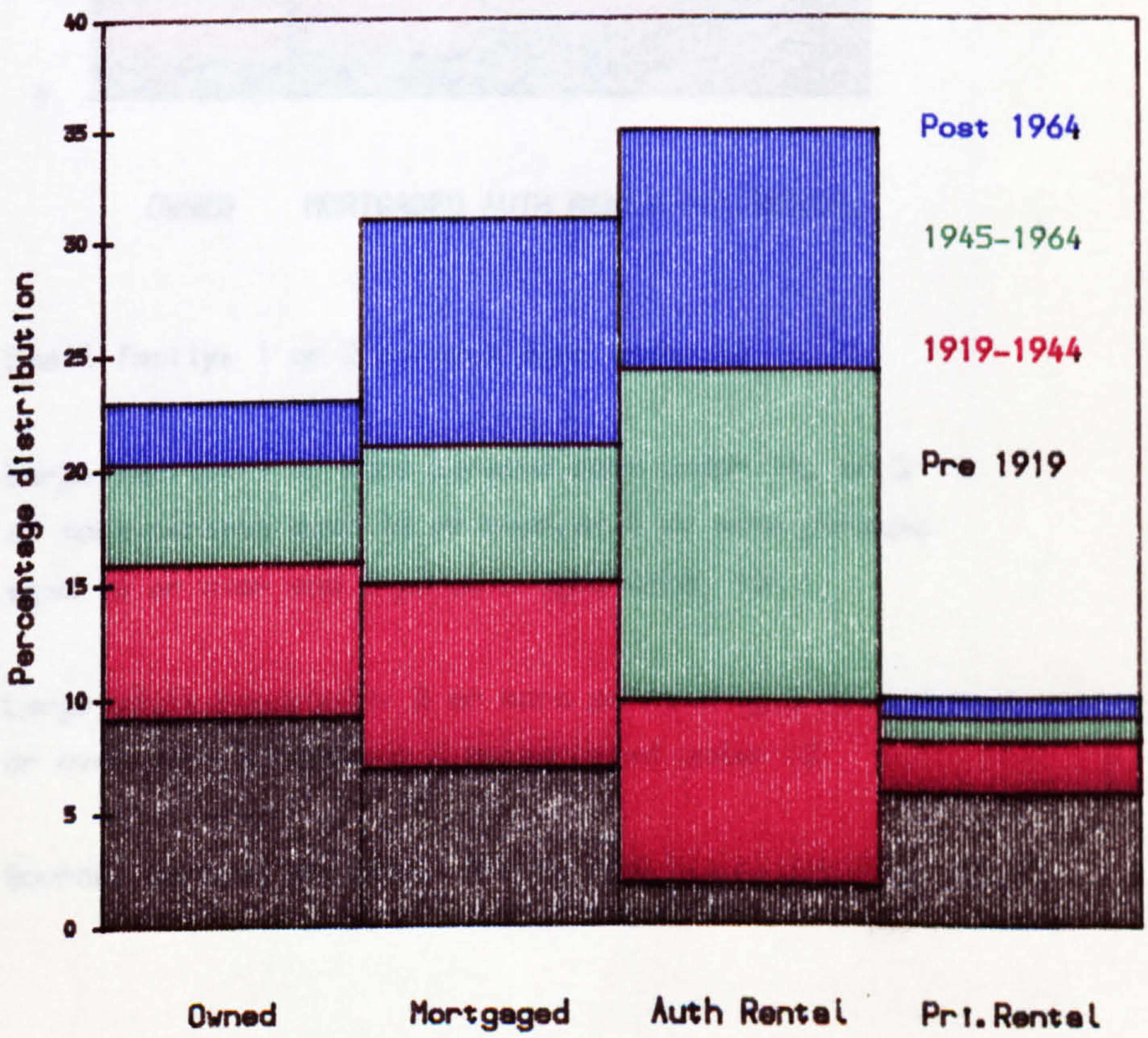
Table 4.14 Degree days for typical Occupancy Patterns

	Time	Degree days
Full occ.	0 - 24	1971
	6 - 23	1542
	7 - 23	1432
	7 - 24	1526
Intermittent occupancy	6 - 7	213
	7 - 8	209
	8 - 9	196
	6 - 8	314
	7 - 9	303
	8 - 10	282
	16 - 23	661
	17 - 23	601
	18 - 23	537

includes one hour for pre-warming.

AGE OF HOUSES IN U.K.

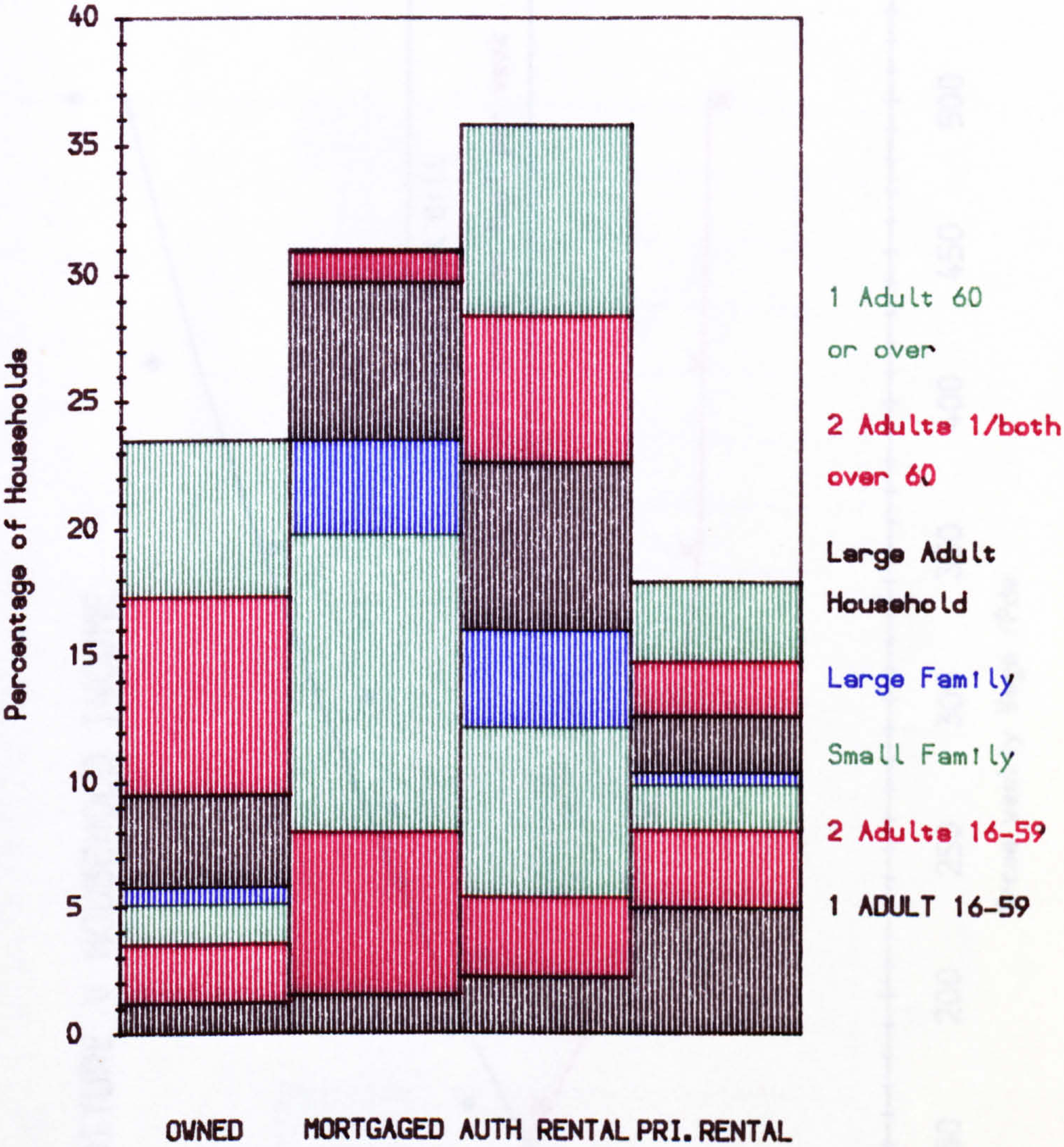




O.P.C.S., 1982

Fig (4.1)

HOUSEHOLD SIZE DISTRIBUTION IN U.K.



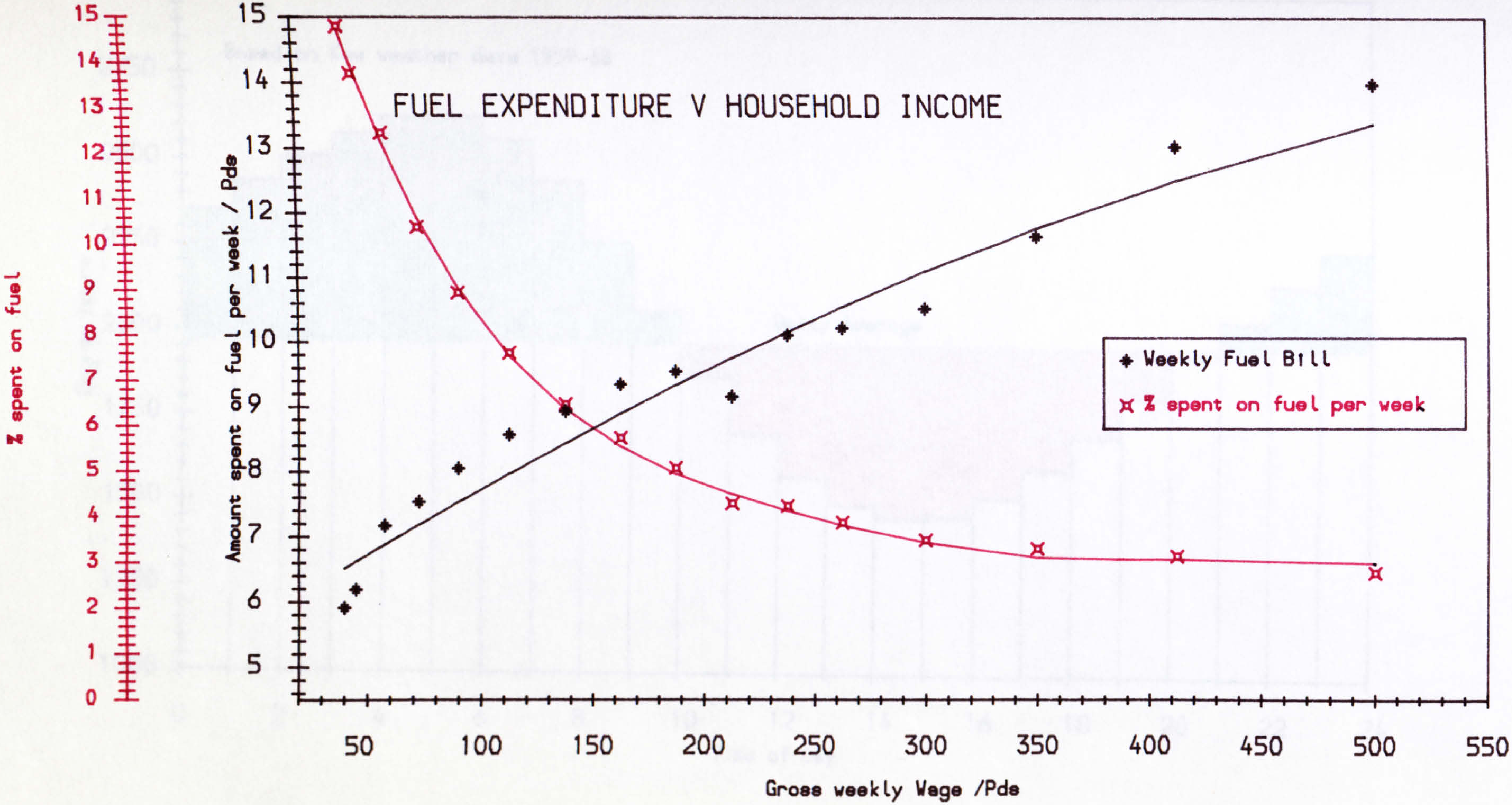
Small family: 1 or 2 persons aged under 16

Large family: 1 or more persons aged under 16, or 3 or more persons aged 16 or over, or 3 or more persons aged 16 or over and 2 persons aged under 16

Large adult household: 3 or more persons aged 16 or or over with or without 1 person aged under 16

Source: General Household Survey 1981

Fig (4.2)



Family Expenditure Survey 1983

Fig (4.3)

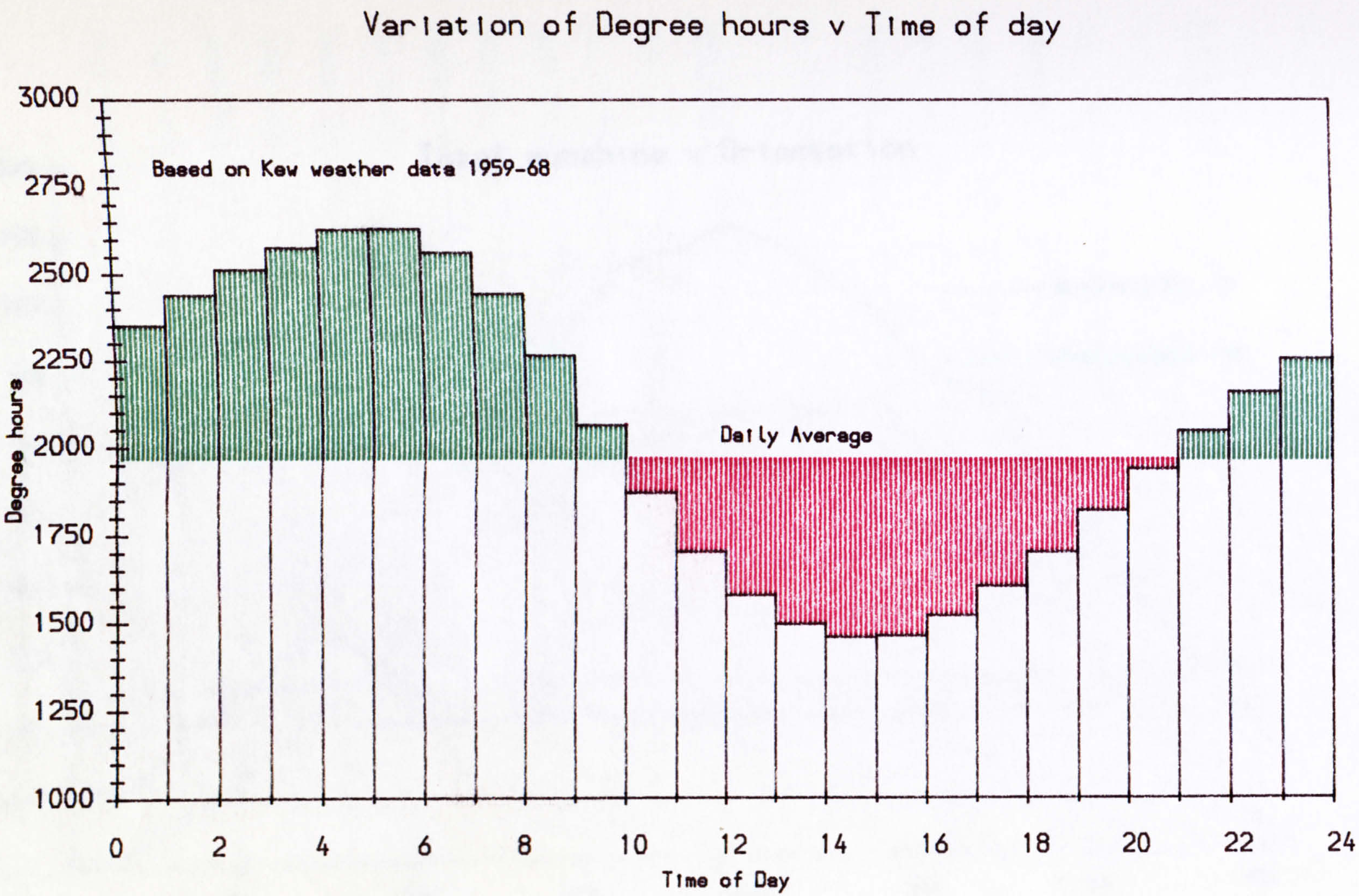
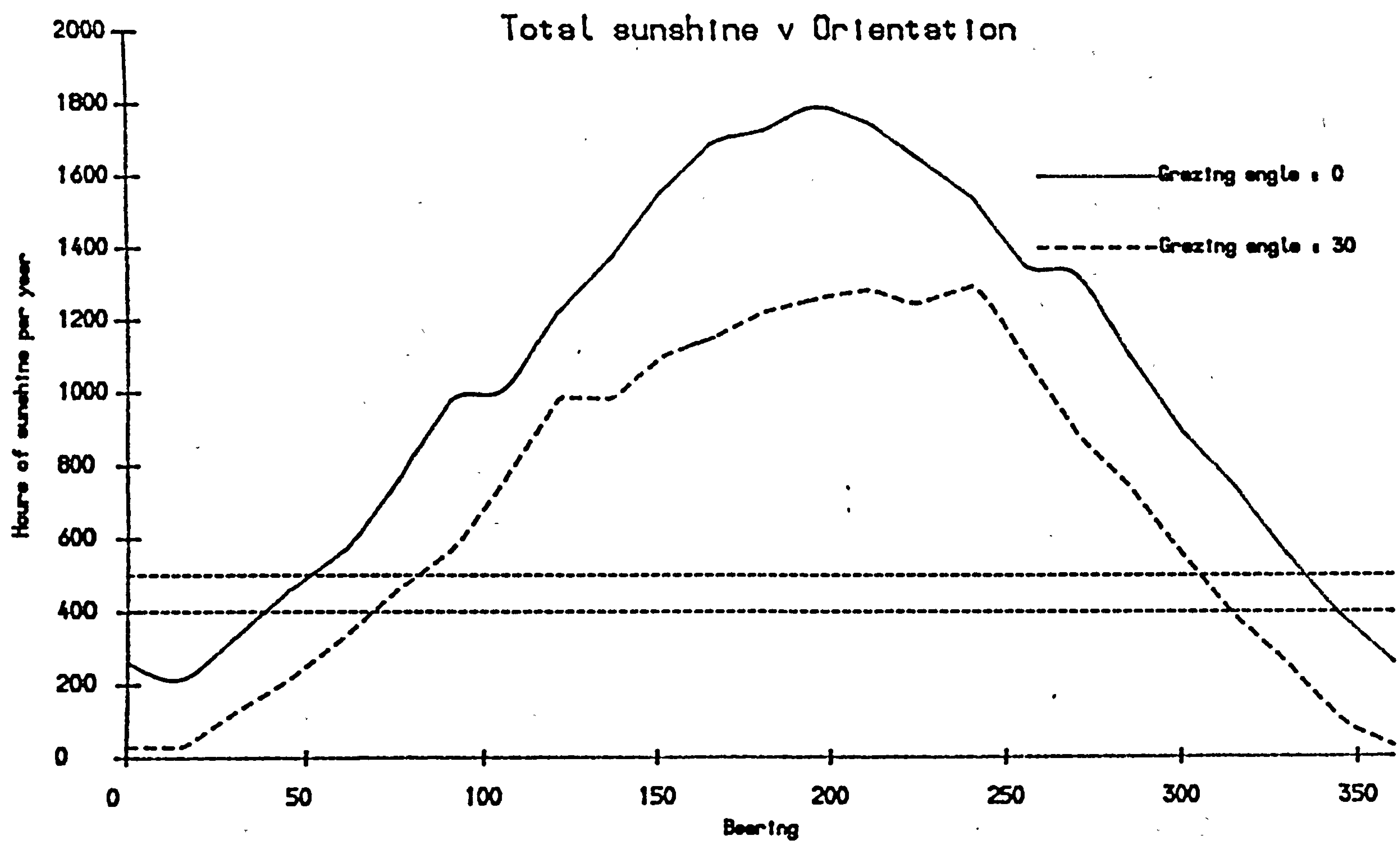

Variation of Degree hours v Time of day
Based on Kew weather data 1959-68
Daily Average
Degree hours
3000
2750
2500
2250
2000
1750
1500
1250
1000
0
2
4
6
8
10
12
14
16
18
20
22
24
Time of Day

Fig (4.4)



Total sunshine v Orientation
Grazing angle : 0
Grazing angle : 30
Hours of sunshine per year
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
50
100
150
200
250
300
350
Bearing

Figure (4.5)

CHAPTER 5 EXPERIMENTAL ANALYSIS OF A CONSERVATORY

5.1 Introduction

It was decided that the behaviour of a conservatory should be examined by investigating the characteristics of an existing conservatory. This would give an indication of the actual solar gain to a conservatory under normal weather and povide the basis for checking the computer model which was being developed.

5.2 The Conservatory

At the outset of this research, it had been hoped either to erect an ´off the shelf´ proprietary conservatory such as is available from any Do It Yourself shop or garden centre, in the grounds of the University with an attached shed for storing the logging equipment, or to design and build a conservatory on the roof of the Department of Civil Engineering. Both of these options would have given control over the size, orientation and overshadowing of the conservatory and possibly facilitate the variation of any of these components. One of the early schemes proposed the construction of a small conservatory on a turntable to examine the effect of different orientations.

Permission was sought from the University for the undertaking of these plans but neither were permitted. There was no suitable land readily available and it was feared that a conservatory on the roof of the department would pose an unnecessarily high risk because it might be blown away in high winds.

It was therefore decided to seek a suitable existing conservatory for monitoring. Through the kindness of the Architectural practice, Stephen George and Partners, permission was granted to use their Victorian greenhouse at the end of the garden of the Partnership's offices in Leicester.

5.2.1 The Leicester Greenhouse

The selection of the greenhouse at Leicester posed several problems, in particular its location, some 100 miles from Leeds. This would therefore necessitate a carefully prepared monitoring timetable. The greenhouse would have to be converted to resemble an attached conservatory. Additionaly, it was feared that the greenhouse may for long periods be overshadowed by local buildings.

The greenhouse is a large building built towards the end of the nineteenth century.

The greenhouse is 3.8m deep by 9m wide with a central bay that forms the entrance. It abuts a large garden wall to the rear (north) and on the western side. The other two elevations are glass upon a brick wall of height 700 mm. The main structure is of timber. All vertical glazing is openable, the upper level by means of a wrench system. The greenhouse was divided in two sections of area of about one third and two thirds by a party wall of timber and glass with an openable single door between the two areas. The smaller area was at the eastern end and had an outside door to the east elevation. It was decided to use this area for monitoring. The greenhouse was in a poor state of repair, with some broken panes of glass covered with polythene and several rotten timbers. Despite this, the greenhouse was in full use by the partnership's gardener for the propagation of seedlings and the growth of grape vines. The smaller section was used primarily for storage of garden tools. Bonchair's work (1986) shows this to be ideal.

There had been electricity to the greenhouse but it had been disconnected for some time. The greenhouse faced 22^{o} west of south which was considered to be acceptable.

The gardener permitted the author full use of the smaller section under the understanding that we left each others halves undisturbed.

5.2.2 Overshadowing

Before any work could be undertaken, the problem of overshadowing had to be investigated.

The greenhouse is at the end of the back garden of the house at 170, London Road, Leicester. The house is at an altitude of 88 m above sea level in what was once a Victorian residential area. Although much of the area to the north is built up with terraced houses, most of the houses have large gardens, thus reducing the density of buildings. To the south of the house there is a large open area: Victoria Park. The area is shown on Ordnance Survey map SK5903.

It was thought that the overshadowing caused by neighbouring buildings was not severe and was in fact typical of what might be expected in many residential areas.

There was however a fear that the parnership's offices would cause unacceptable overshadowing of the greenhouse during the late autumn and early winter.

The main part of the partnership's office reaches a maximum height of 12m, 33m from the greenhouse in south-south-western direction. There is a lower narrow building of width 6m and maximum height 11.5m at a distance of 18m again in a south-south-western direction from the greenhouse. Attached to the western garden wall was a garage of height 5.5m, 10m from the greenhouse. The garden wall was 2.8m high running south-south-west attached to the greenhouse to the west and 5m from the greenhouse to the east.

To estimate the effect of buildings on overshadowing of a building, a computer package developed by Pour-Deihimi (1984) at Leeds was used. This produced a grid plan at a scale of 1:100 of the heights above which overshadowing at ground level would occur.

The larger building caused no overshadowing since the sun was close to its zenith at the time that it crossed it. Additionally the garage caused no overshadowing and the garden wall would have a slight effect at dawn and dusk in September and March. The smaller building would cause some overshadowing from mid November through to mid February between the hours of 12.00 and 14.00. The neighbouring buildings were likely to obscure the early morning and late evening sun during the months of low solar altitude. There would be no time when the whole of the greenhouse was in the shade.

This level of overshadowing was not considered to be unrepresentative of what might be found for many conservatories. Since the actual solar radiation that the greenhouse received was to be measured it was considered that the greenhouse would be acceptable for this research.

5.2.3 Alterations to the Greenhouse.

The greenhouse had to be repaired. This was done by a local builder who, whilst producing acceptable work, was late starting and took longer than anticipated, thus putting back the start of the monitoring by some three to four months.

New glass was put in where necessary and the woodwork was repaired or replaced. The greenhouse was repainted and the electricity connected. Light and power were run through to the small section. An extractor fan was fitted above the external door in the small section.

Whilst the repairs were being undertaken, the builders constructed a partition wall 1.15m from the back wall to the full height of the greenhouse of plywood and insulating board of an overall U value of 0.4 W/m^2K.

Vents were inserted top and bottom of size 220mm x 150mm at 450mm and 2700mm centres from the floor. They were 300mm centres from each end. The builder placed grilles over these vents which were subsequently removed. There was a small door between the front and back areas which could be padlocked.

The windows were fixed permanently closed. Where the window seal was poor, this was improved with the generous use of mastic. The roof and the two side walls of the back room were insulated with 50mm polystyrene insulating board. This was sufficiently opaque to darken the room considerably thus eliminating most of the solar gain that the north side might have received.

The interconnecting door between the two halves of the conservatory was kept permanently closed, egress was via the outside door on the eastern side.

5.3 Data Collection

The greatest problem with the monitoring of the conservatory was the collection of the data. A simple and robust data logger would be required which could work for long periods unattended. The original solution had been the use of a small micro-computer but this was ruled out because of the need for the presence of an operator and the computer's possible unreliability. Eventually a Christie CD248 data logger was selected.

A range of possible channel numbers was available for the data logger but it was thought that the smallest option: 32 channels, would suffice. An inbuilt E.C.M.A. standard cassette recorder was chosen for data storage. This had the advantages of providing a compact, high volume medium in a sturdy package that could be sent through the post and could be easily loaded and reloaded by anybody familiar with an ordinary cassette player. The cassettes could hold substantially more than an audio cassette and the data logger checked each set of data on the tape before sending the next block. During the course of the monitoring data was not corrupted on any occasion.

The cassettes would be read on the Texas Silent-type reader connected to the University of Leeds' Systime computer and then transfered to the Amdahl main-frame computer for examination. The data were stored in sections headed by the day and time followed by the channel number and the actual temperature read by the logger (with the exception of the two solarimeters whose data was in the form of micro-volts). Before starting the measurements all the thermocouples were calibrated by comparing the data logger's monitored temperature with the temperature at 100°C and 0°C. A small program was used on the Amdahl to correct the temperatures.

The data logger was over five months late in arriving. This was because Chistie promised to deliver a machine that they had not finished designing. In exasperation an old Credshire data logger was used. This read data onto a facit paper tape punch which was very reliable. The same was not true of the Credshire data logger.

Scanning 25 channels every 20 minutes necessitated changing the paper tape every 72 hours which meant that at least two visits a week to Leicester were necessary. Several sets of data were found to be useless since the logger had failed at an early stage of its 72 hour scan. When the Christie logger finally arrived it was immediately put into service despite being unable to connect it to a printer as was initially intended. This was left since another delay had to be avoided.

At each scan, the data logger read the radiation on the vertical and horziontal using two solarimeters on the conservatory placed facing in the same direction as the conservatory. The outside air temperature was also measured.

A grid of fishing line was set up in the conservatory running from one side to the other. These were at heights of 15mm, 1940mm and 2905mm from the floor and at a distance of 1000mm from the partition wall for the lower two levels and 500mm from the partition wall for the upper. Along each of these were placed three thermocouples on the left, centre and the right. The partition wall had thermocouples set just into the surface at the same heights as the air thermocouples. The air temperature of the logging room was monitored, as was the neighbouring section of the greenhouse. All thermocouples had radiation screens covering them.

5.4 Time Span

The original start date for the logging of the conservatory had been intended to be the 21st of June 1984. This was ambitious but it was hoped to get data for the summer so that summer overheating could be examined. Sadly, the alterations to the conservatory were not completed at this time and were not finished until September 1984. The starting date was therefore delayed. However, the logger had not been delivered by then.

The data collection was therefore started in October 1984 with the old Credshire data logger. Much of the data that were collected during this time were lost due to data-corruption by the logger or general failure of the machine. An electricity cleaner was connected in series to the power supply and this solved many of the problems.

The new data logger was set up in the second week of December 1984 and worked well from then. Scanning was continued non-stop until the end of March 1985 when the logger was returned to Leeds.

Since it had been impossible to examine the problem of overheating during the previous summer, the conservatory was monitored through much of the summer of 1985, from June to September.

A scan of all of the channels was taken every 12 minutes. One side of a data cassette would be full after 4 days, hence one weeks data could be stored on one cassette. The tape was turned over mid-week by John Morphy of Stephen George and Partners and either sent by post of collected by the author every week.

5.5 Results

A graphical analysis of the monitored data was made directly for each day via a suite of programs written on the Leeds Amdahl computer. These enabled an almost instant picture of the behaviour of the conservatory and the weather conditions for each day. Figures (5.3) to (5.20) show a selection of typical daily results. The day of the year was output by the logger and this was transferred directly to the graphs. The days correspond as below.

Day 355	20 December 1984
Day 356	21 "
Day 357	22 "
Day 16	16 January 1985
Day 17	17 "
Day 18	18 "
Day 19	19 "
Day 22	22 January 1985
Day 23	23 "

Day 40	9 February 1985	
Day 41	10 "	
Day 42	11 "	
Day 43	12 "	
Day 60	28 February	1985
Day 61	1 March	1985
Day 225	12 August	1985
Day 226	13 "	
Day 227	14 "	

The graphs are divided into three distinct sections. The top section shows the weather data for that day in terms of the air temperature and the horizontal and vertical radiation. The outside air temperature (TAO) daily swing has been calculated from the data.

The second section has the measured conservatory temperatures. The conservatory air temperature (Tcons) is an average of all of the measured air temperatures in the conservatory. The logger room (back room) air temperature (Tlog), the temperature of the back wall (Tbwall) and the temperature of the conservatory floor (Tfloor) are shown.

The bottom section shows the temperature differences across the conservatory. These are the temperature difference between the top and bottom air vents between the two sections of the conservatory (vents) which are an indication of the air movement between the two rooms, the temperature difference across the dividing wall (Wall), an indication of heat transfer through the wall and the temperature difference between the conservatory air and the outside air (Cons-Air).

All of the graphs are plotted using points at 12 minute intervals over 24 hours.

5.5.1 Survey of results

Days 355 to 357 Figs(5.3)-(5.5) represent a mild early winter period in mid December. The sky was generally overcast and thus the solar input is relatively low. The outside air temperature is high and relatively steady with low daily swings. The conservatory air temperature follows fairly closely the pattern of the outside air temperature suggesting that this is of greater effect than the solar input. There is a small increase in conservatory air temperature with the solar input and it is generally higher than the outside air temperature.

The swing of the conservatory air temperature is greater than that of any of the other temperatures monitored in the conservatory. The air temperature of the logger room, the conservatory floor temperature and the back wall temperature are all higher than the conservatory air temperature at times of zero solar input for day 355 and the first half of day 356. This is because of the accrued storage and the effect of the solar input on day 355. After noon of day 356, when there is practically no solar input, these temperatures become lower than the air temperature of the conservatory since they have not been charged up in any way. On day 356 the conservatory air temperature is very close to the outside air temperature.

The conservatory air temperature is consistently higher than the outside air temperature, albeit marginally at times.

The temperature difference across the wall is positive (higher in the conservatory than the back room) during the daylight hours and after the sun has set. On days 355 and 356 the difference is negative: the back room is losing heat to the conservatory.

There is little or no difference in temperature between the top and bottom vents suggesting very little air movement.

Day 16 to 19, Figures (5.6) to (5.9) show a very cold spell with intermittent sunshine. On the coldest days 16 and 17 there is a consistent and large difference in air temperature between the conservatory and the outside air. The colder the outside air temperature, the greater the benefit of the conservatory suggesting a significant contribution as a buffer zone. This is irrespective of the solar gain. Although the conservatory air temperature rises up with solar input, the net difference in air temperatures reduces at this point. This appears initally suprising. In effect, the sun is contributing to the stored energy of the fabric which helps to maintain higher conservatory temperatures. During such cold periods the conservatory's major contribution is as a thermal store to produce a significant buffer zone.

Despite sub-zero outside air temperatures, the conservatory only dropped below zero on day 17.

Most of the time there is a positive flow across the wall except during the night of day 17, however once there is some solar input the flow returns to being positive. It appears that providing there is some solar input, the conservatory is very useful during very cold weather. This is likely to be the case, examining Kew Weather data (Meteorological Office, 1969) times of very cold weather occur during cloudless days, when there is cloud cover the air temperature is higher since there is a much smaller net radiation loss to the sky.

Day 22 and 23, Figures (5.10) and (5.11) show mild winter days with high solar input. The conservatory air temperature is significantly affected by the solar input, increasing rapidly with it. The conservatory air temperature swing is much greater than the outside air temperature swing although that of the logger room is slightly lower, being buffered by the conservatory. There is a positive heat flow across the wall when the sun shines. The back wall temperature remains fairly steady, higher than the conservatory air temperature during darkness and lower when the sun shines. There is a delay in the peaks of the logger room, back wall and floor temperatures of about one hour compared to the conservatory air temperature.

Days 40 to 43, Figures (5.12) to (5.15) show a cold day of negligible input followed by three days of strong sunshine. On this occasion the conservatory air temperature drops below freezing due to the very cold external temperatures but there is a consistently significant improvement in air temperature within the conservatory compared to outside. This temperature difference remains for most of the day and only drops when the sun rises leading to a marked improvement in the outside air temperature, the outside air temperature now approaching that of the conservatory. This long period of temperature difference between outside and the conservatory is of great use. It would provide prewarmed air during the period of solar input and provides a significant buffer zone for 24 hours a day.

Although the conservatory air temperatures are low, in this case between $-2^{\circ}C$ and $7^{\circ}C$ these are a significant improvement on the outside air temperature and may therefore contribute to a significant reduction in the heat requirements of the house.

Days 60 and 61, figures (5.16) and (5.17) show mild days with a low solar input followed by a high solar input. During day 60 there is a general downward trend of the conservatory temperatures until the solar input of day 61. Once the sun has set on day 61 the conservatory temperatures are all significantly higher than for the 24 hours previously.

Days 225 to 227, Figures (5.18) to (5.20) are three days of strong sunshine in summer. The outside air temperatures are high, peaking at 24 °C and the conservatory temperatures are also significantly high. The conservatory becomes as hot as 34 °C which would cause discomfort if it is to be used. The air temperature of the conservatory follows fairly closely the path of the solar input.

During the evening the outside air temperature has dropped to 12 °C suggesting that the conservatory may be able to provide some useful heat. During the day some form of ventilation is required to reduce the temperature. This can be achieved with the use of a fan drawing warm air in to the store for use in the evening.

The direct irradiance is at its highest when there is no cloud cover. During the winter months it is at this time that the outside air temperatures are at at their lowest. The householder gets maximum input at time of maximum need.

5.5.2 Air Flow

It was assumed that there would be a natural flow through the ducts caused by buoyancy. For this reason, the temperature difference of the air around the conservatory was measured and the temperature difference between the vents is shown on the graphs.

An attempt was made to calibrate the pressure drop across the vents.

However an experiment that was undertaken during several sunny days appeared to suggest that the amount of natural convection in the conservatory would be very low.

A large amount of rose-bay willow herb was acquired. This is very light and can often be seen to float about in fields for hours on the local wind eddys and currents. It was hoped that this would follow the path of the air flows and thus provide a picture of what was happening to the air flow in the conservatory. This method was first used by Boyle (1982).

Rose-bay willow herb was released into the conservatory on several sunny day when the conservatory was very warm and the back (logger) room was cool in comparison. There was practically no flow of the herb into the back room. The herb did move around the conservatory, most significantly near the windows but it was very unsystematic. It was thought that the presence of the author in the conservatory may be affecting the herb, hence a large amount was released and the author left and closed the conservatory. The herb still moved around but generally in an erratic manner. It remained floating for over an hour but afterwards much was found on the floor of the conservatory but very little on the floor of the back room. This suggests that heat transfer by natural ventilaton is very limited.

On days of little or no sunshine, the herb just gradually floated to the ground.

5.6 Summary and Conclusions

5.6.1 A greenhouse in Leicester was converted to be used as a conservatory. Modifications were made to the greenhouse.

5.6.2 The overshadowing of the conservatory was examined and found to be within the contraints of a typical conservatory.

5.6.3 A Credshire data logger was used for logging from September 1984 until March 1985 and from July 1985 until September 1985.

5.6.4 With low solar input the conservatory air temperature almost always had a higher swing than the outside air temperature or of the conservatory fabric.

5.6.6 The fabric of the conservatory is generally warmer than the conservatory air for the evening and night until about 1.00 to 2.00 h unless there has been no solar input for several days.

5.6.7 When it is very cold, the temperature difference between the conservatory and the outside air is greatest. It is then also very consistent throughout the day.

5.5.8 The air temperature of the conservatory falls below freezing point on much fewer occasions than the outside air temperature.

5.6.9 Providing there was some solar input during the day, it is very rare to find heat flow across the wall from the back room to the conservatory.

5.6.10 When it is mild, the conservatory air temperature is affected greatly by strong solar input, this becomes more even under very cold conditions.

5.6.11 The conservatory always works well as a buffer zone.

5.6.12 No natural convection was found.

CONSERVATORY PLAN 1: 20

DIMENSIONS ARE IN MILLIMETRES

Figure(5.1)

Figure (5.2)

CONSERVATORY SECTION

PAGE MISSING IN ORIGINAL

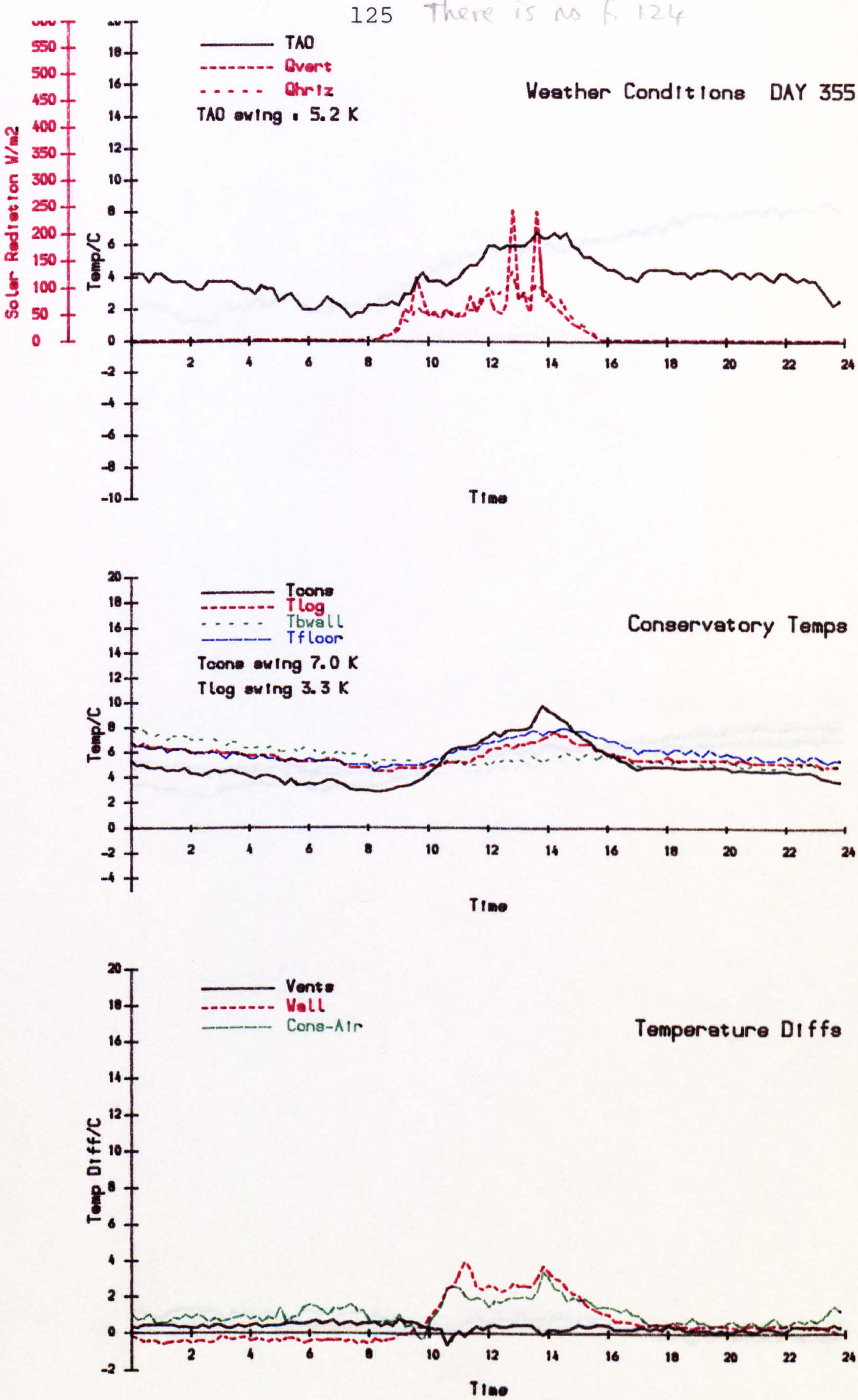


Figure (5.3) Measured Temperatures

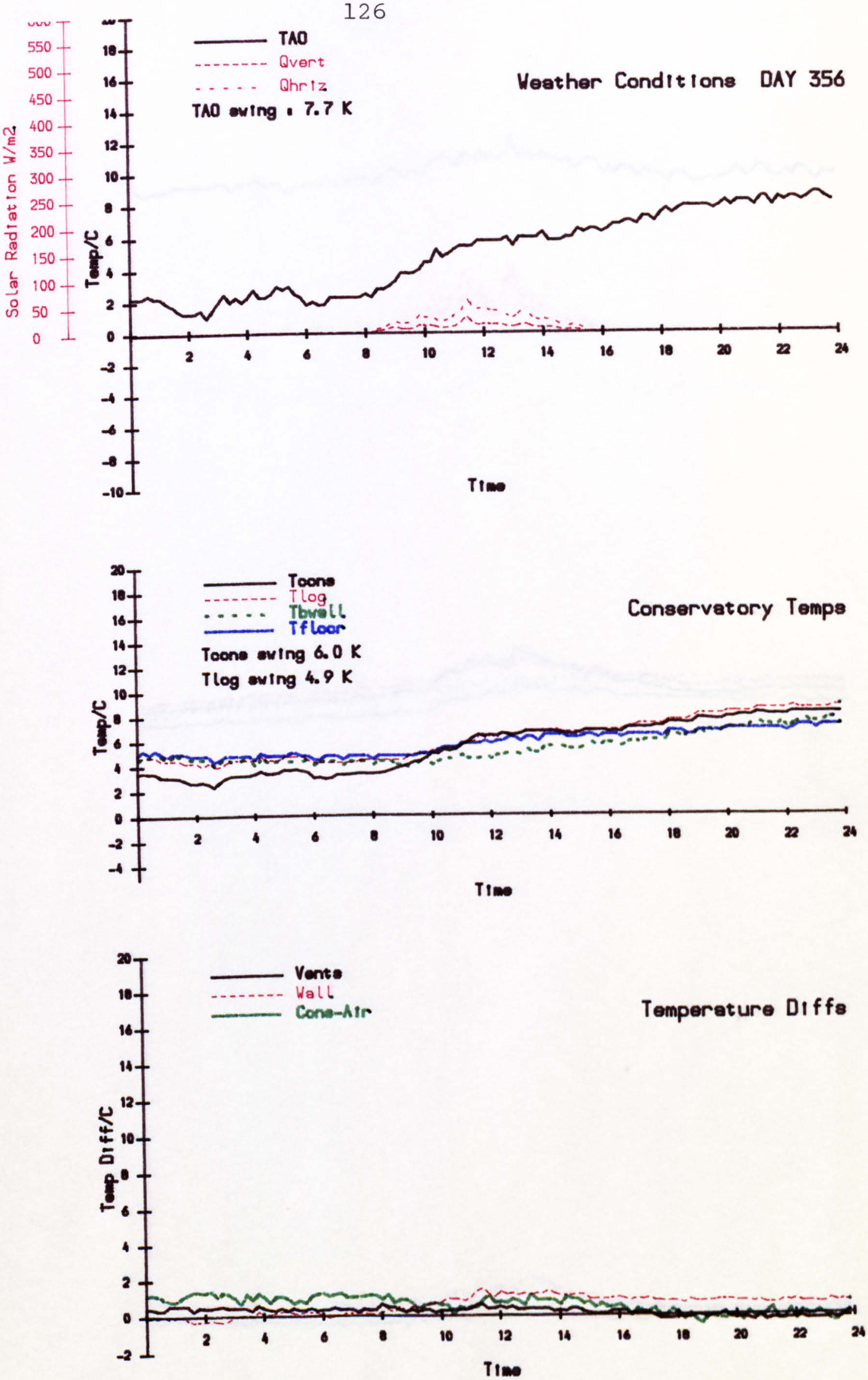


Figure (5.4) Measured temperatures

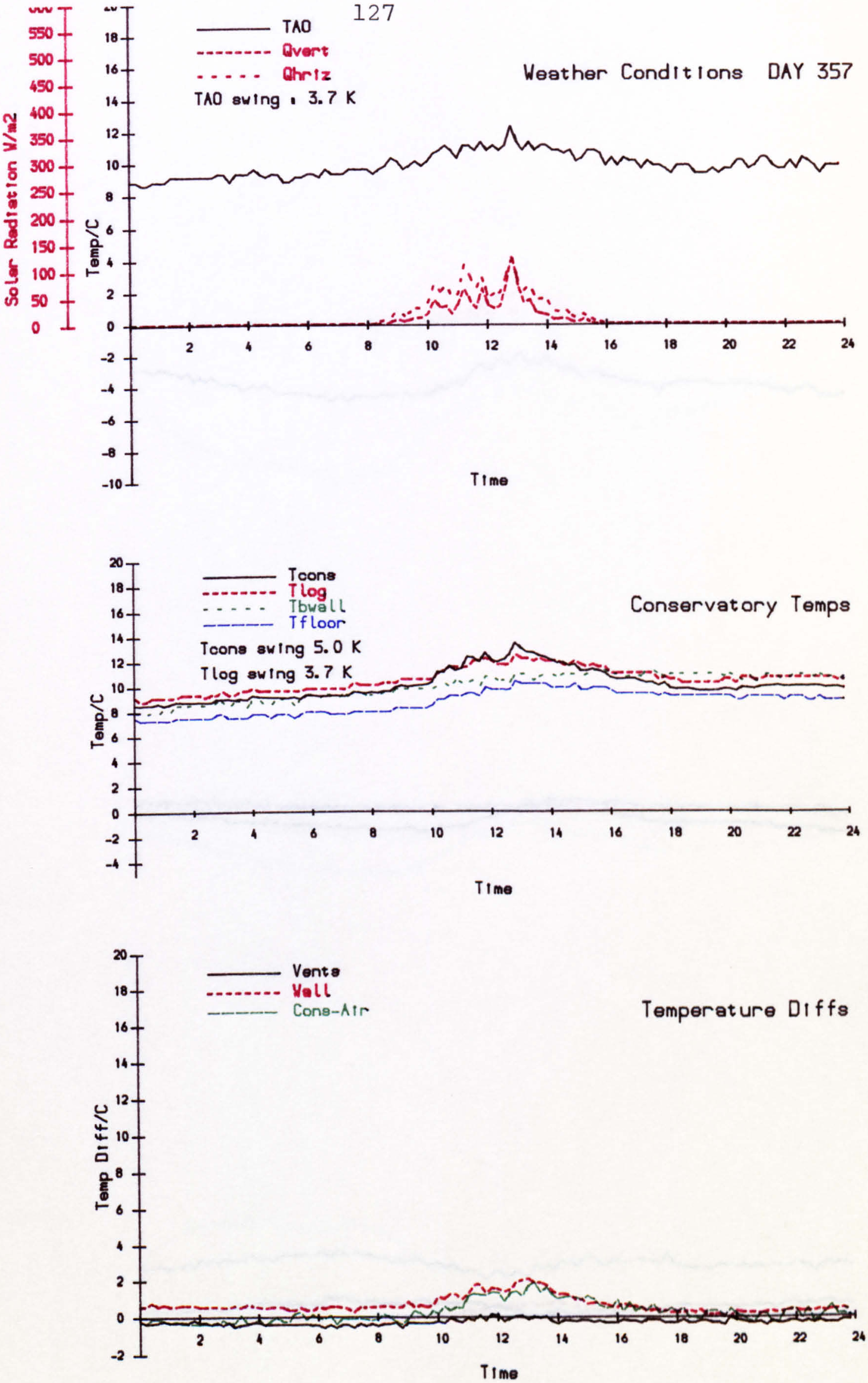


Figure (5.5) Measured temperatures

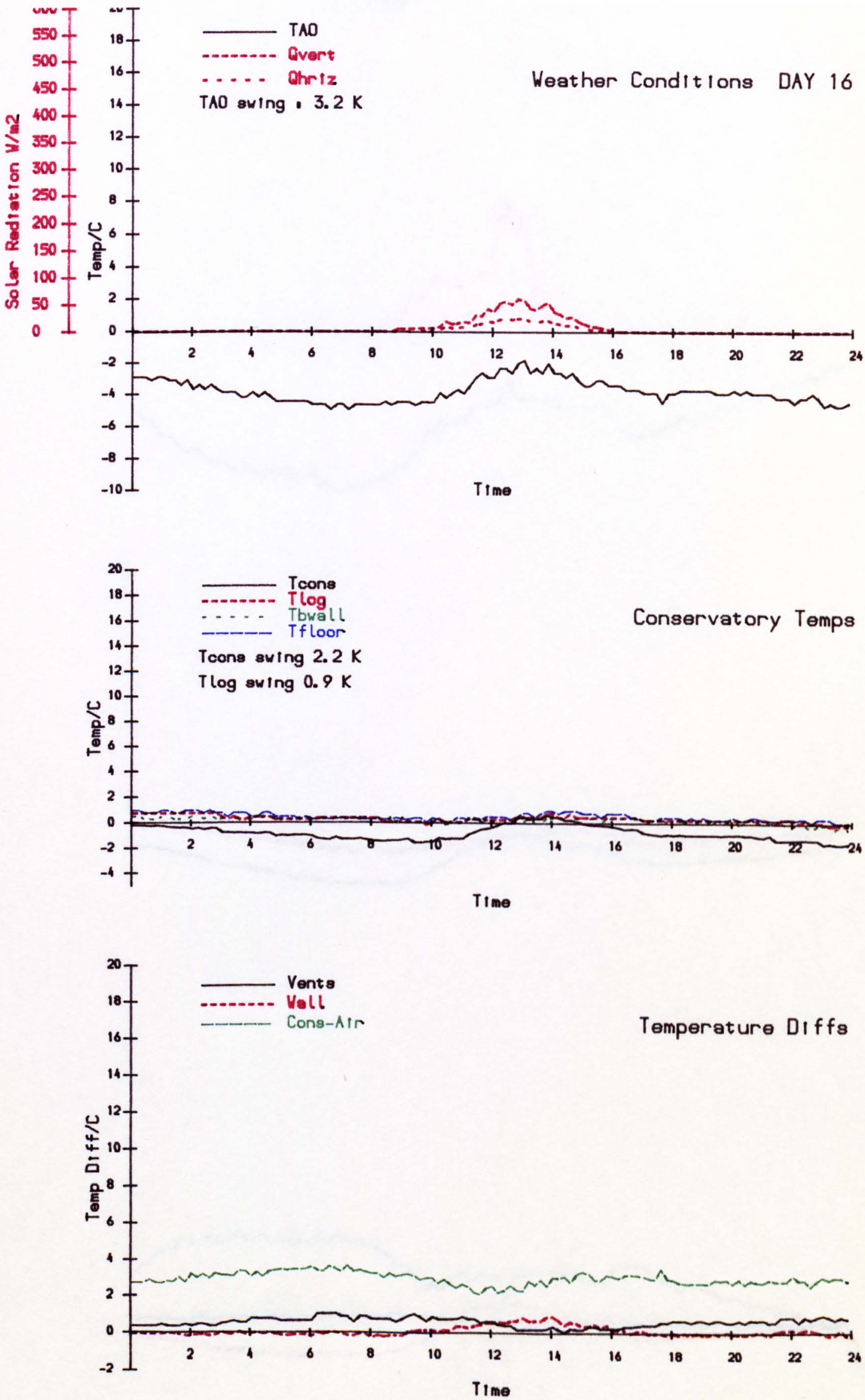


Figure (5.6) Measured temperatures

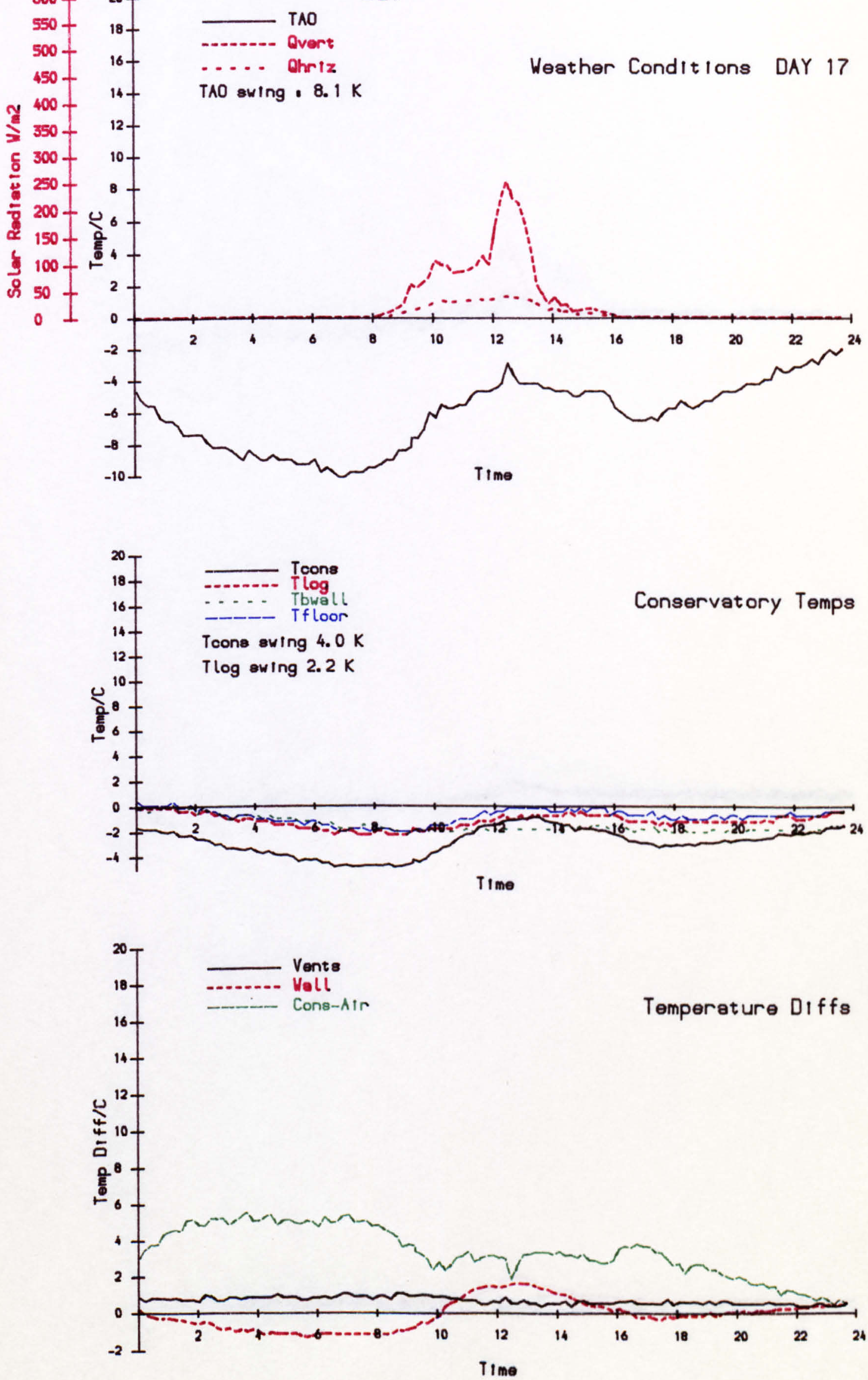


Figure (5.7) Measured temperatures

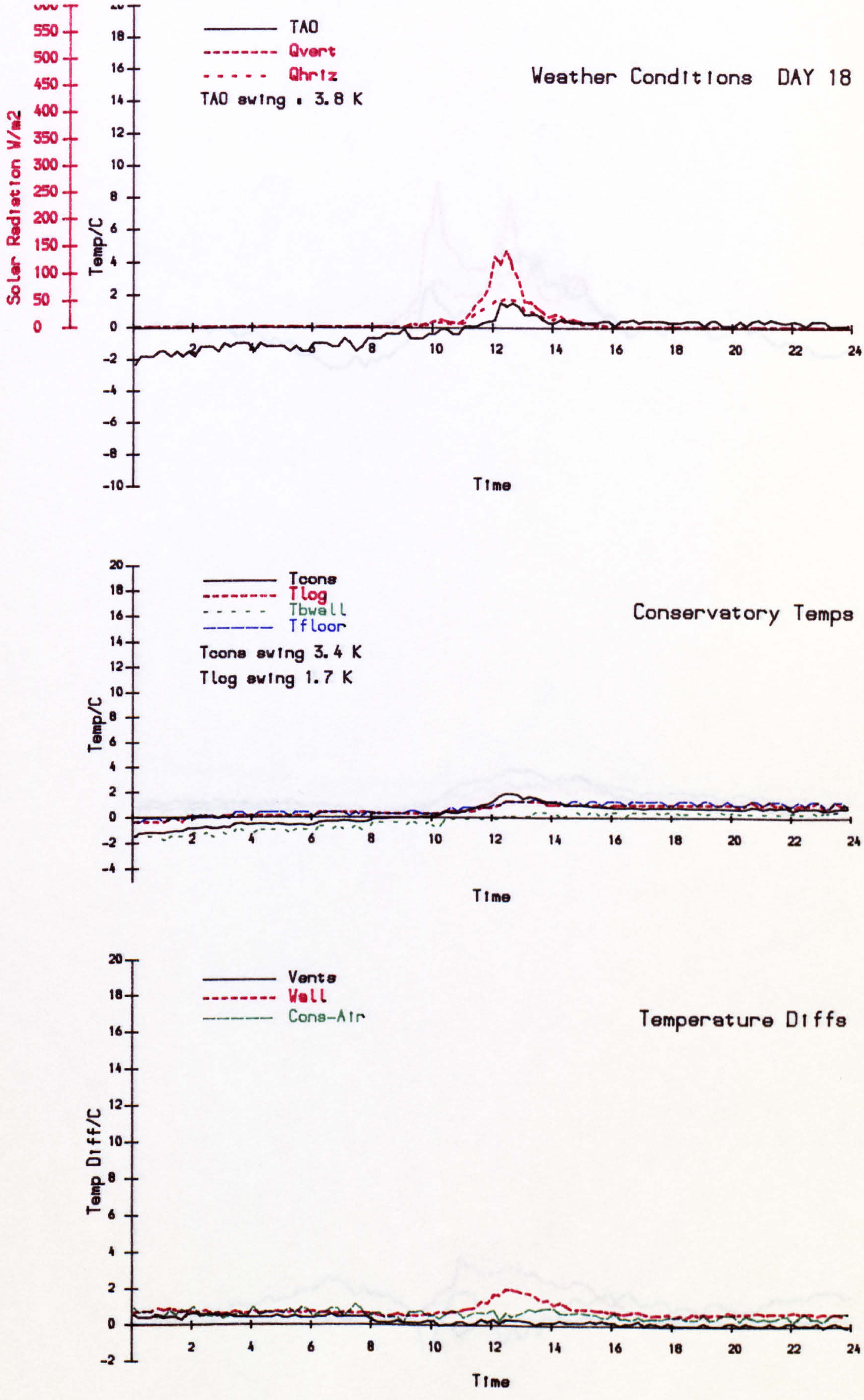


Figure (5.8) Measured temperatures

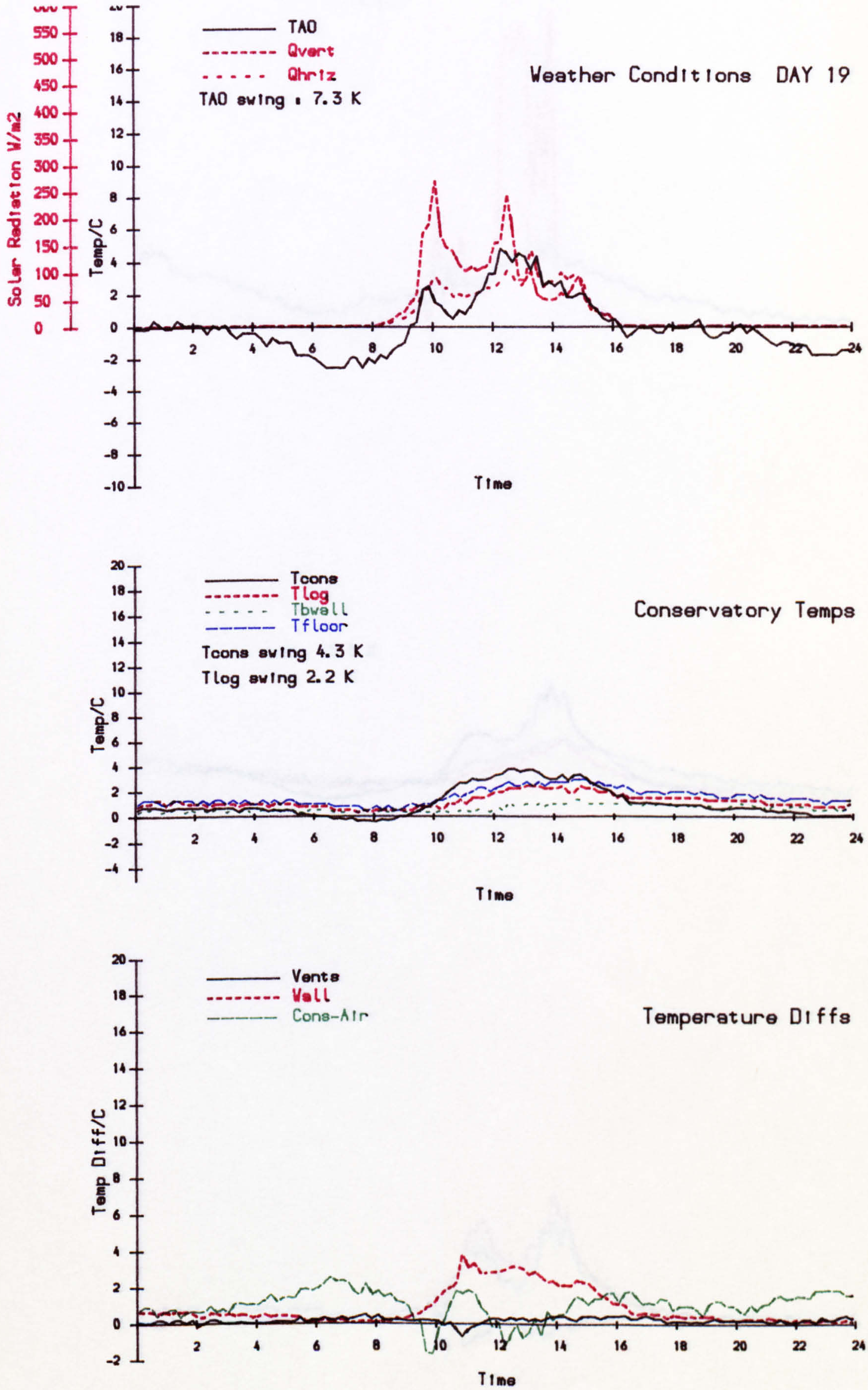


Figure (5.9) Measured temperatures

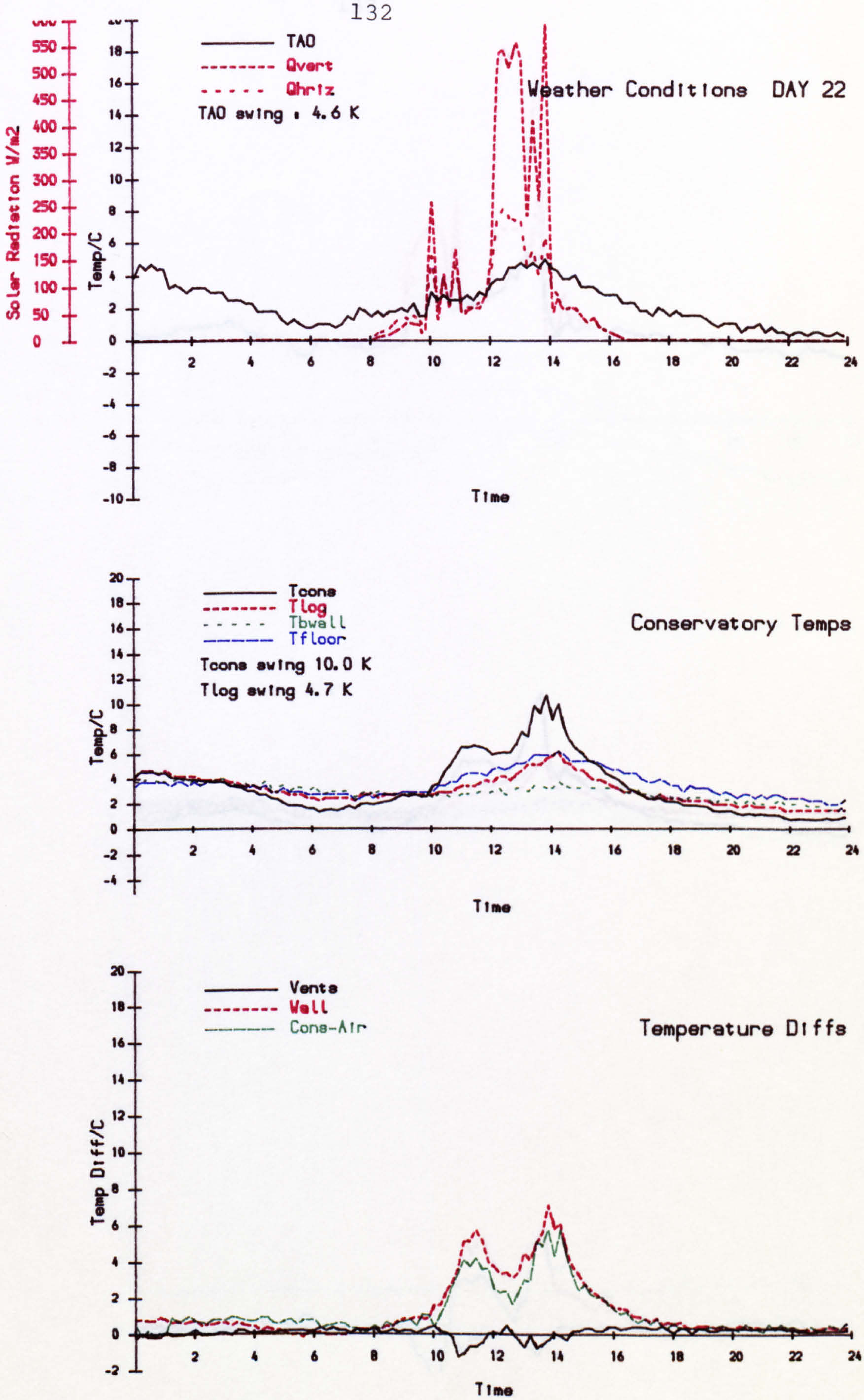


Figure (5.10) Measured temperatures

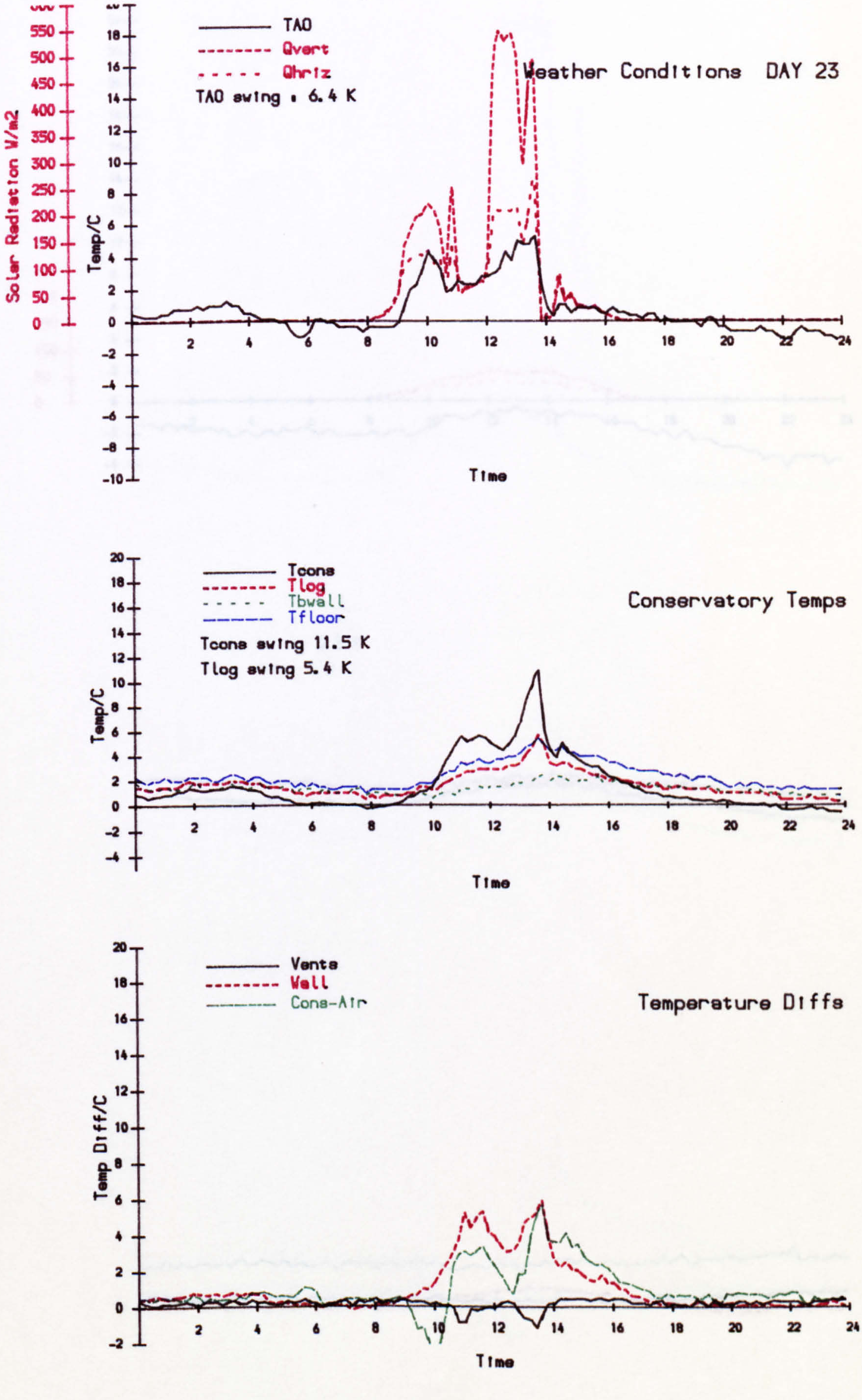


Figure (5.11) Measured temperatures

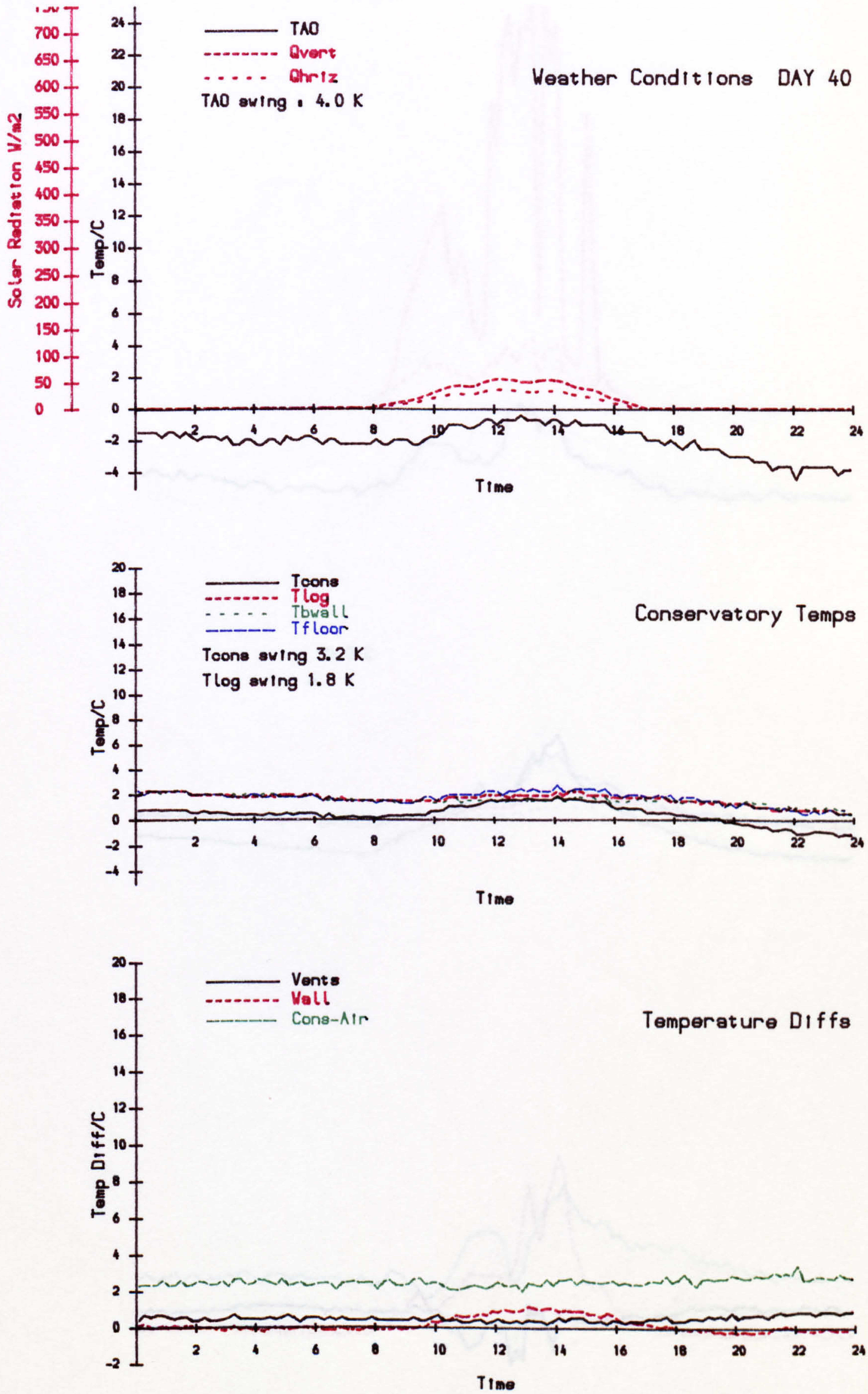


Figure (5.12) Measured temperatures

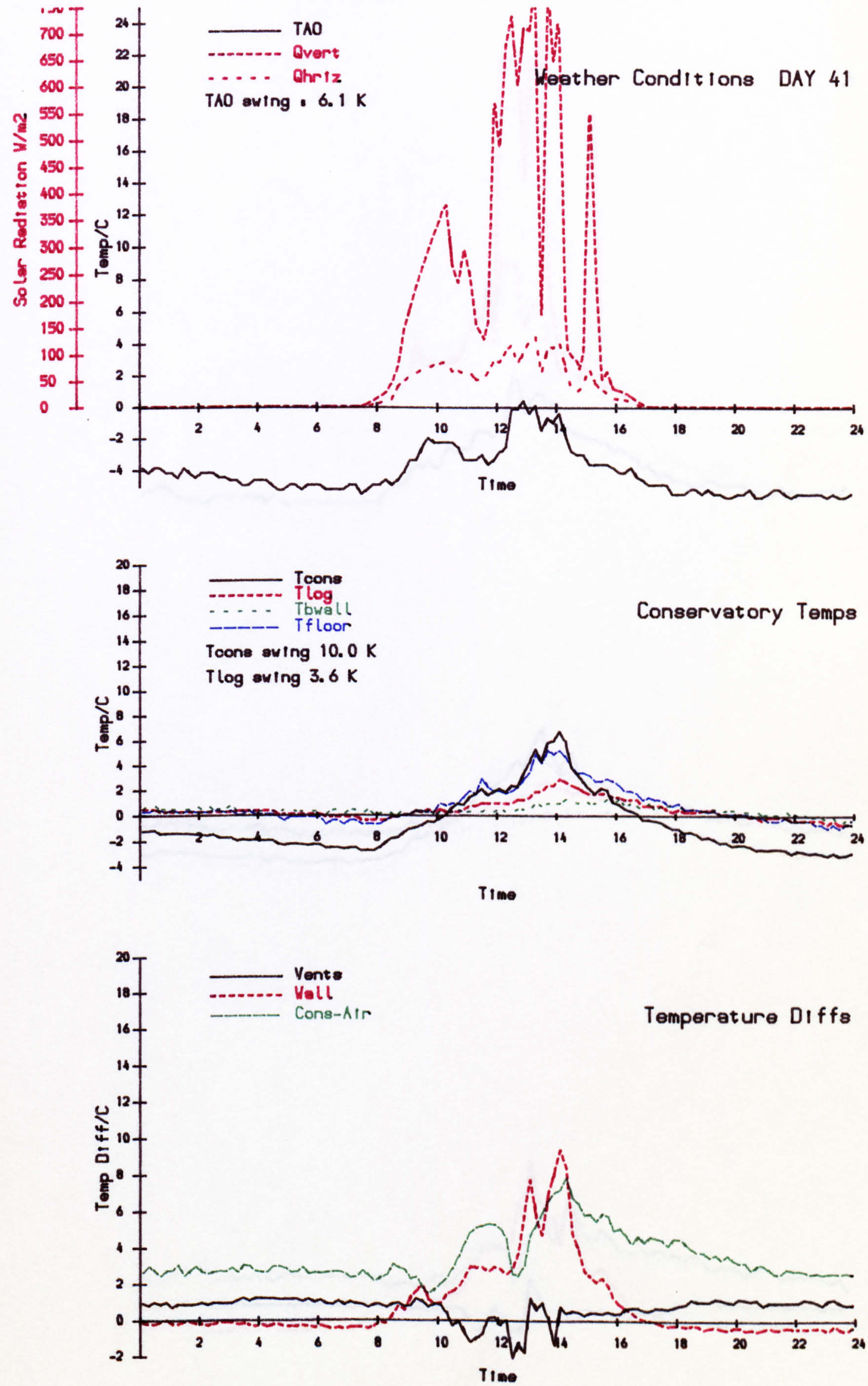


Figure (5.13) Measured temperatures

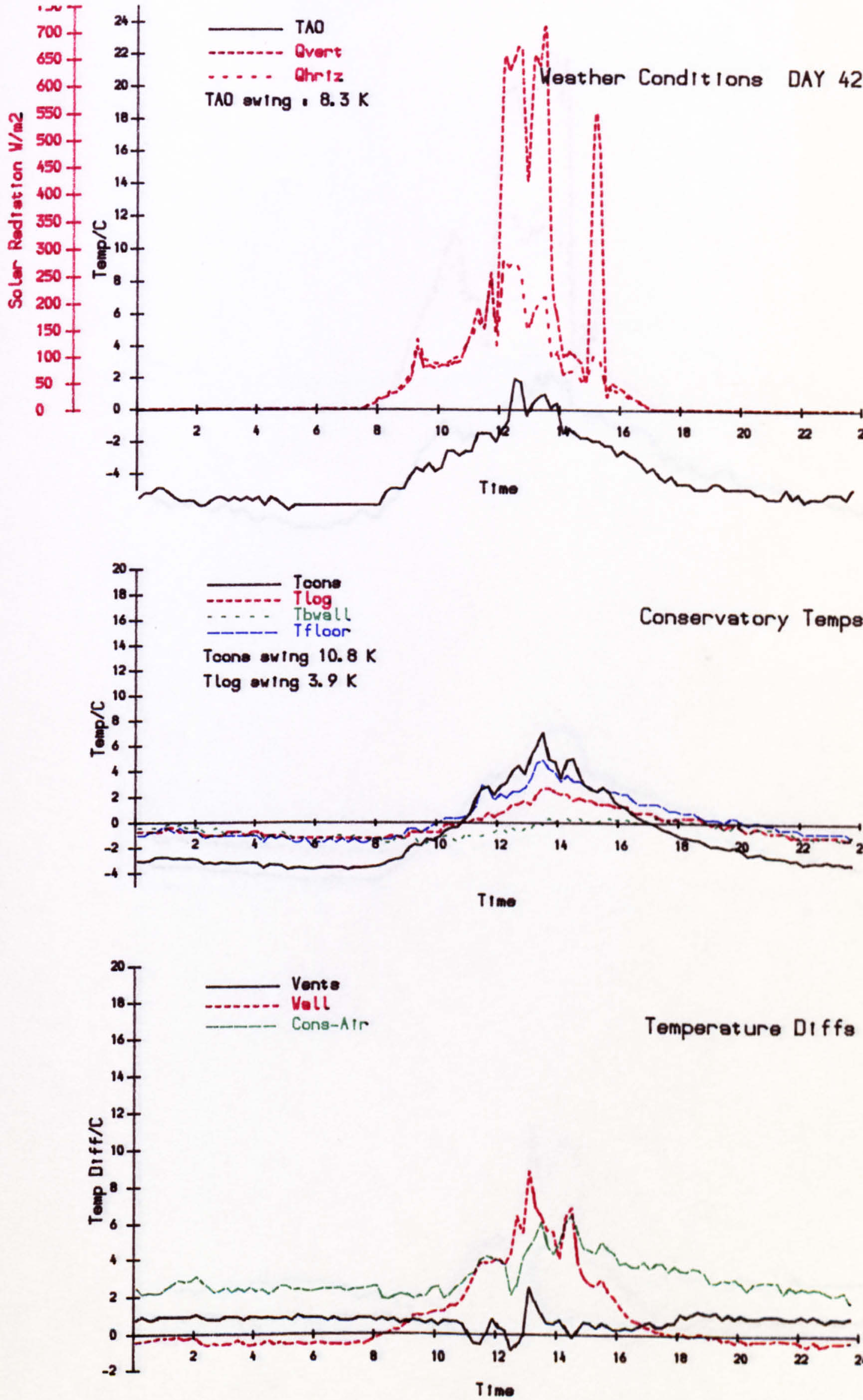


Figure (5.14) Measured temperatures

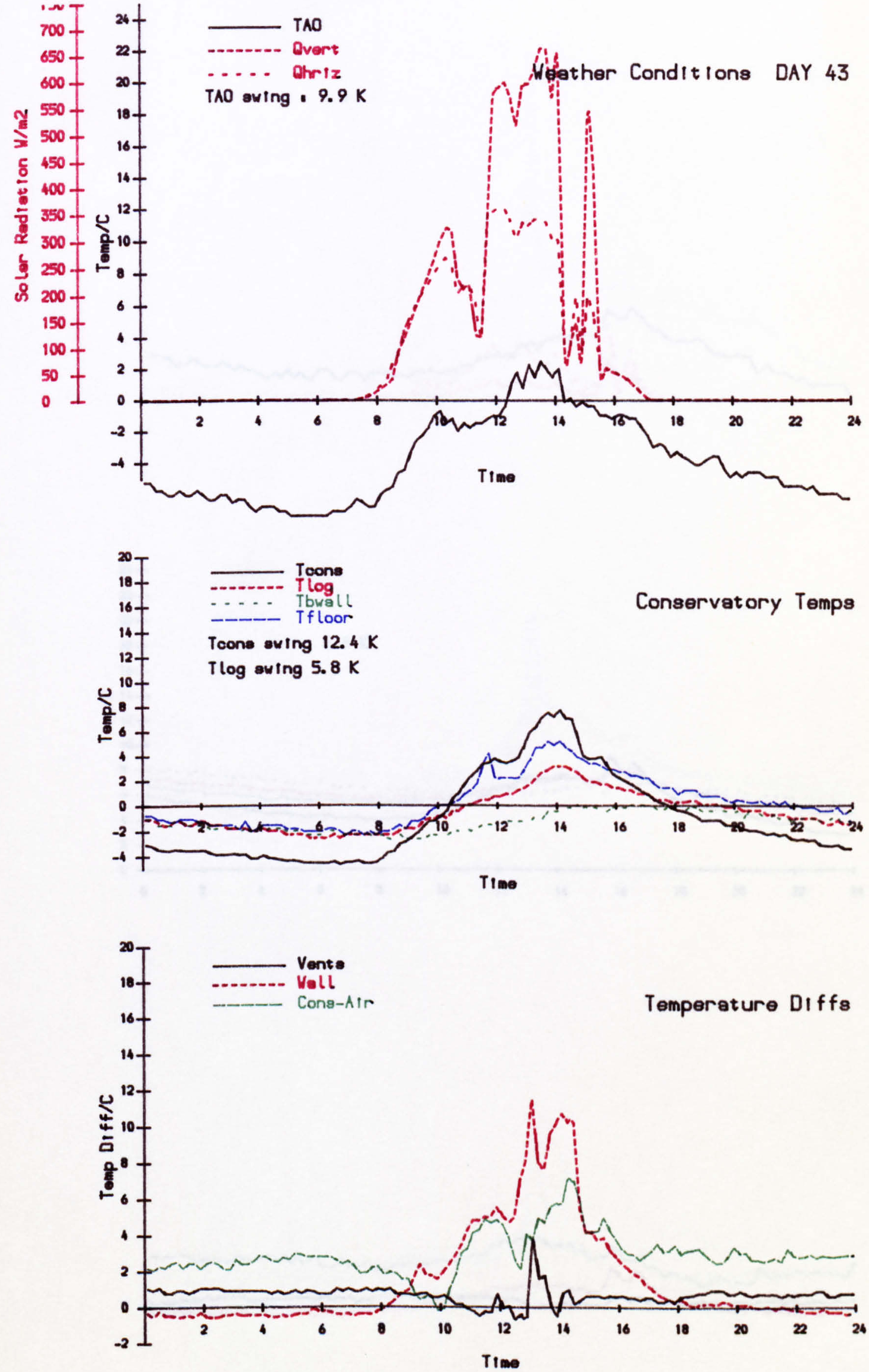


Figure (5.15) Measured temperatures

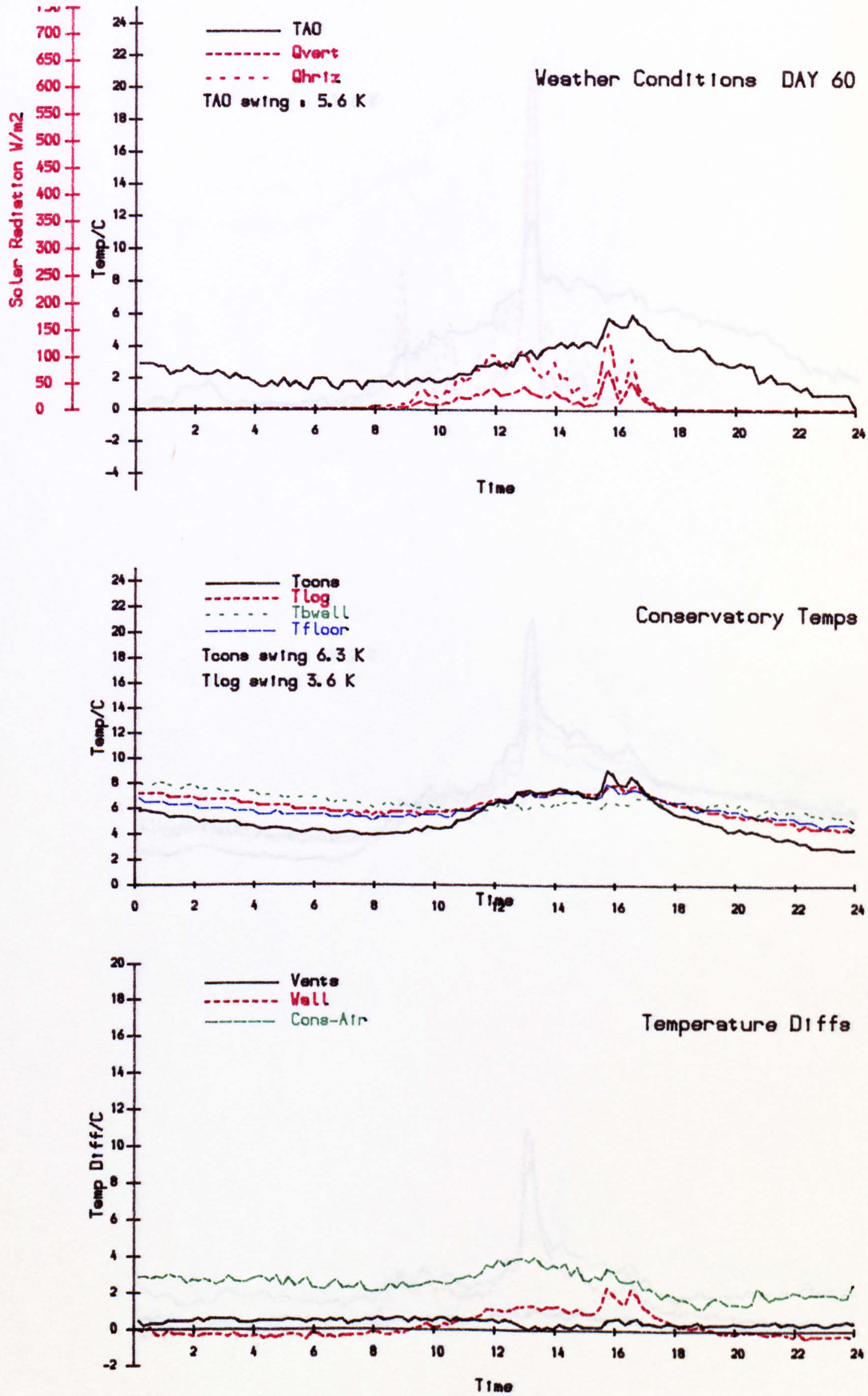


Figure (5.16) Measured temperatures

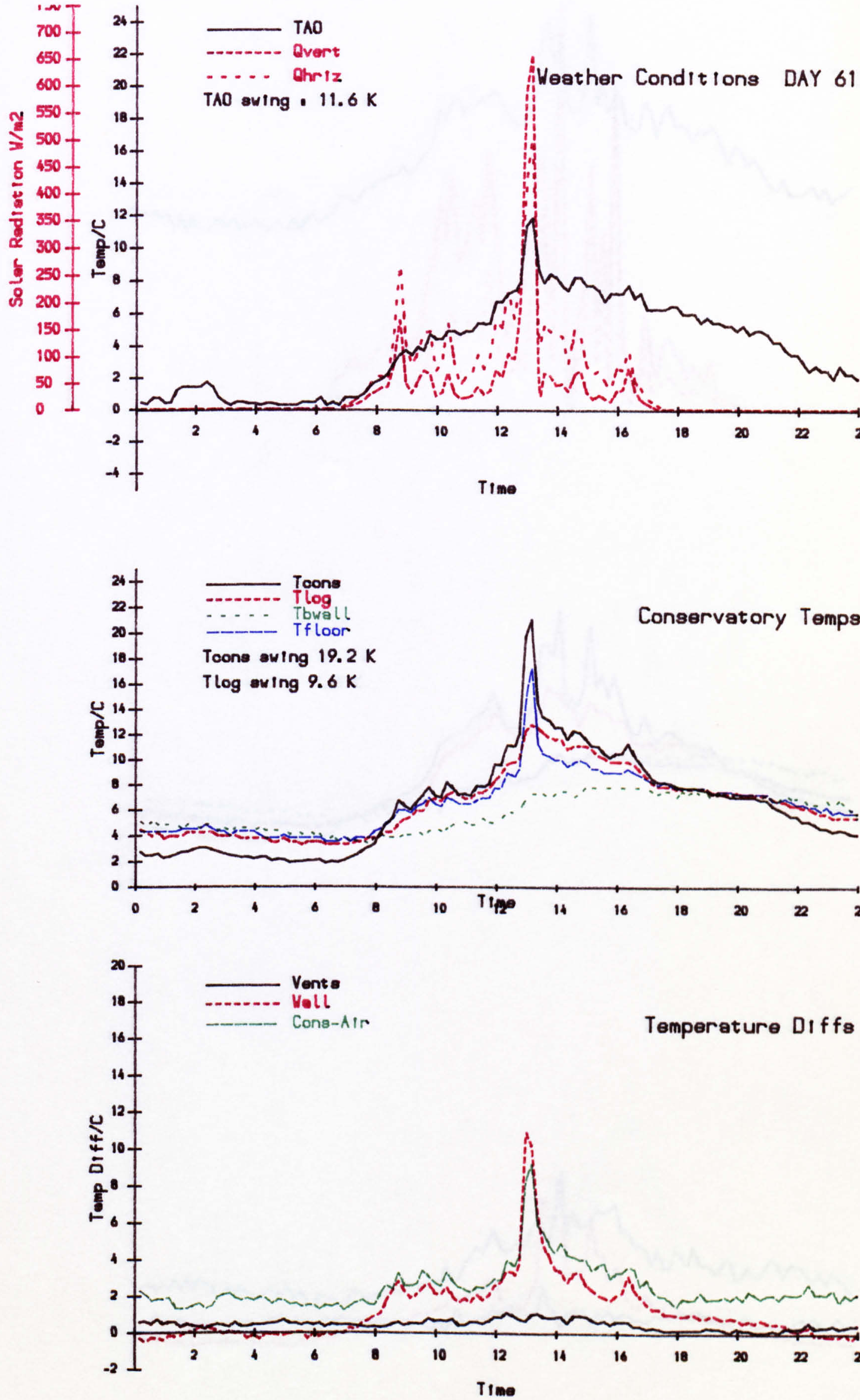


Figure (5.17) Measured temperatures

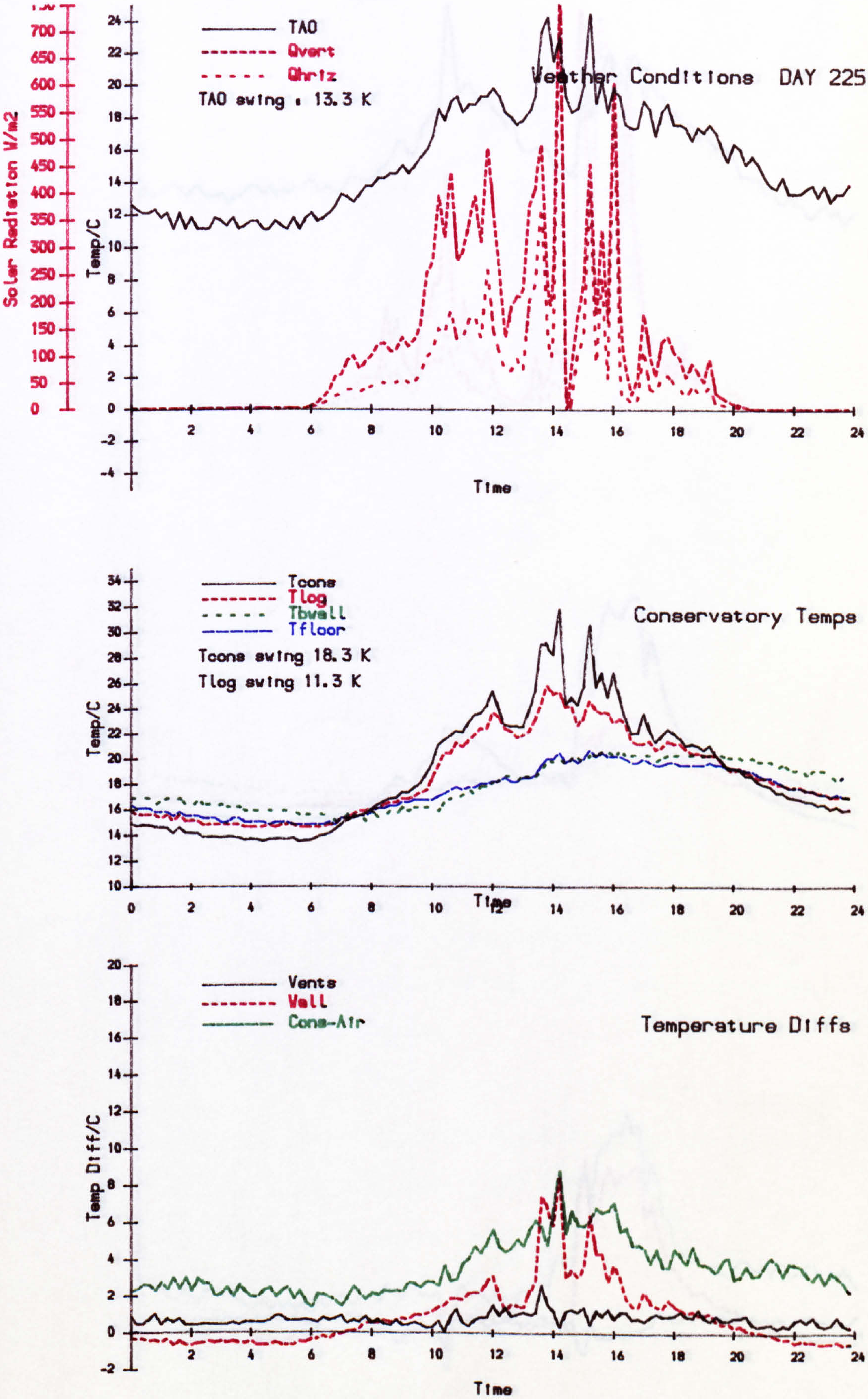


Figure (5.18) Measured temperatures

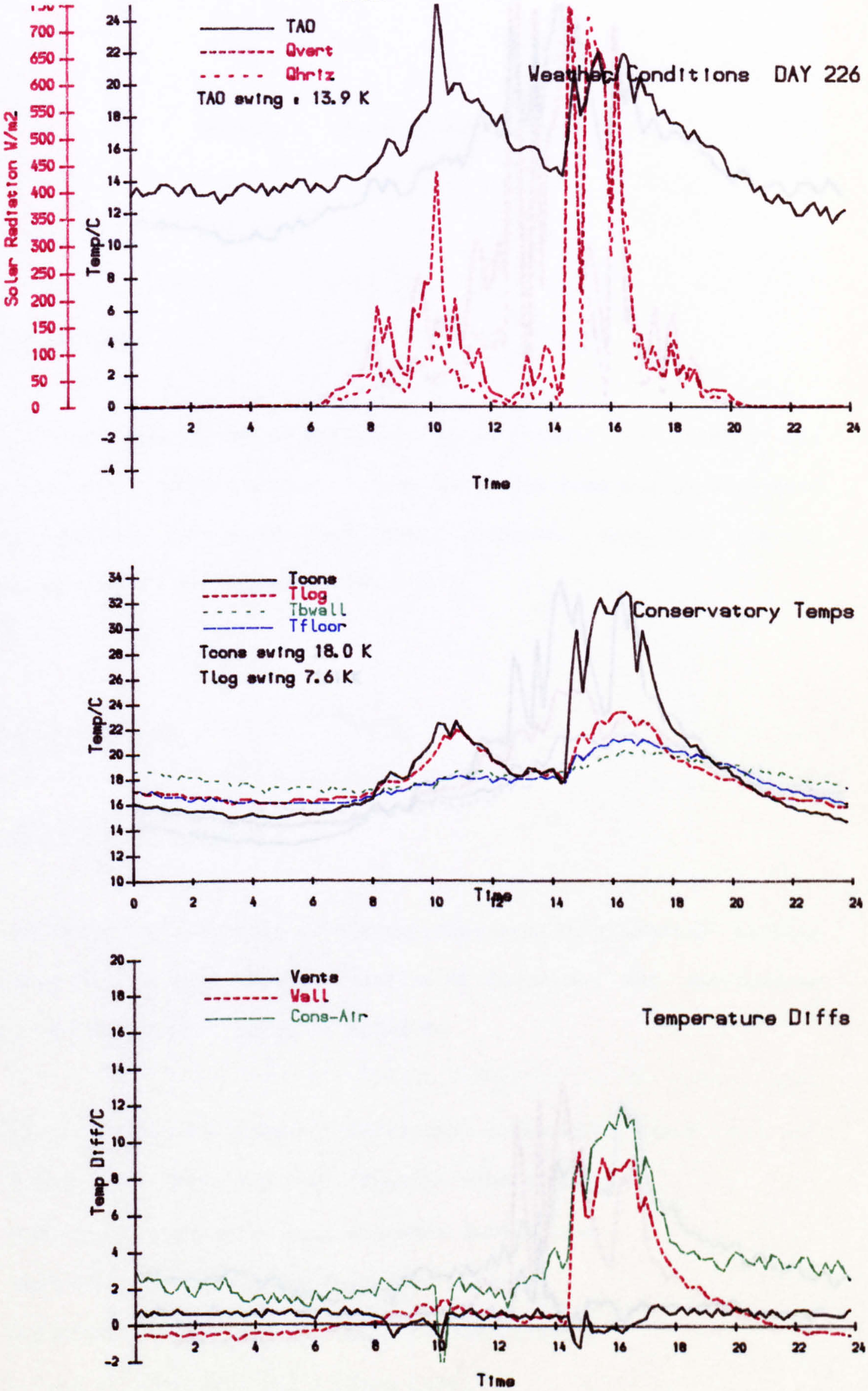


Figure (5.19) Measured temperatures

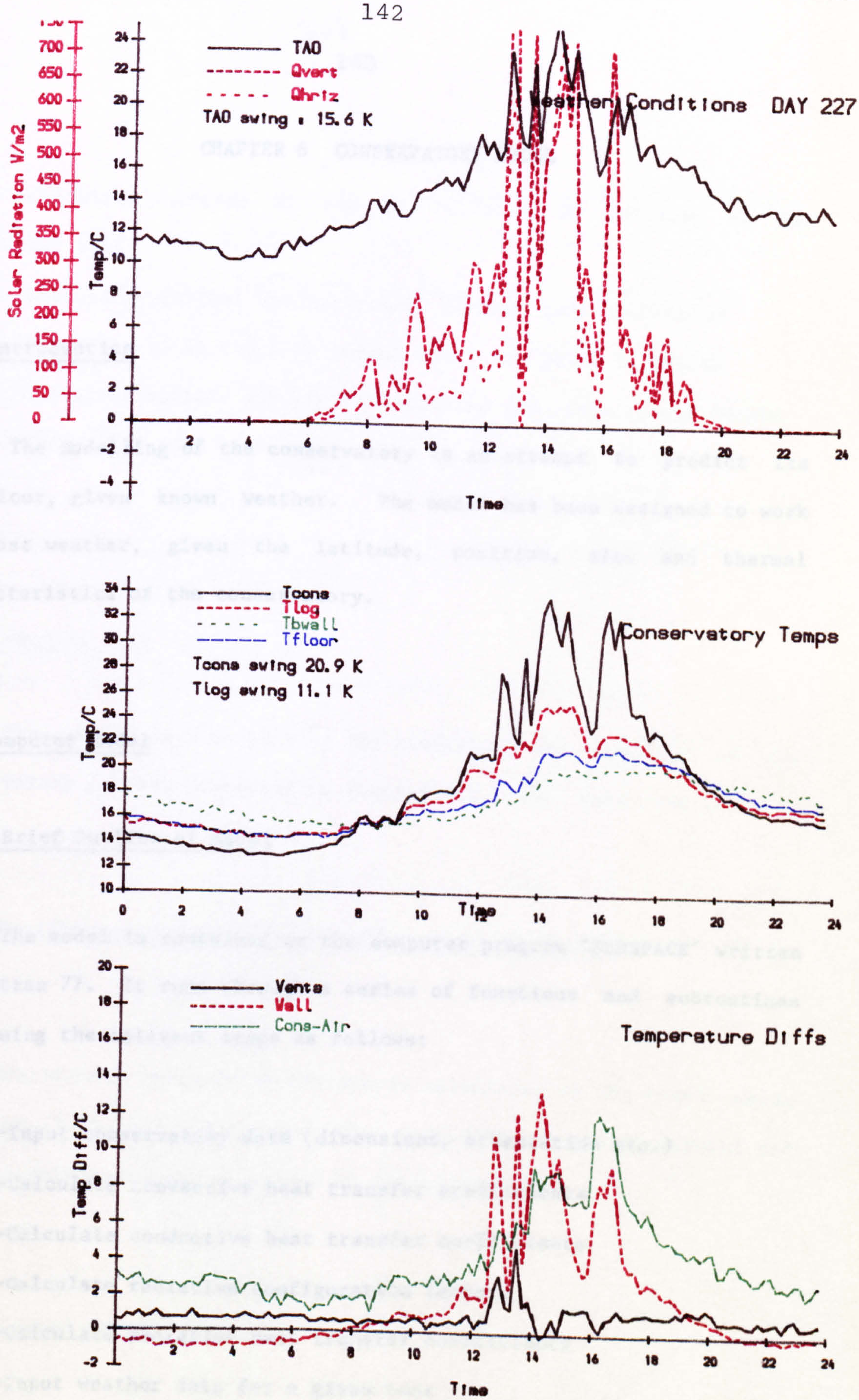


Figure (5.20) Measured temperatures

CHAPTER 6 CONSERVATORY MODEL

6.1 Introduction

The modelling of the conservatory is an attempt to predict its behaviour, given known weather. The model has been designed to work for most weather, given the latitude, position, size and thermal characteristics of the conservatory.

6.2 Computer Model

6.2.1 Brief Outline of Model

The model is contained on the computer program 'SUNSPACE' written in Fortran 77. It runs through a series of functions and subroutines containing the relevant steps as follows:

-Input conservatory data (dimensions, orientation etc.)

-Calculate convective heat transfer coefficients

-Calculate conductive heat transfer coefficients

-Calculate radiative configuration factors

-Calculate radiative heat transfer coefficients

-Input weather data for a given hour

-Calculate total heat transfer coefficients

-Set up heat transfer matrix

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-Calculate convective heat transfer coefficients

-Calculate conductive heat transfer coefficients

-Calculate radiative configuration factors

-Calculate radiative heat transfer coefficients

-Input weather data for a given hour

-Calculate total heat transfer coefficients

-Set up heat transfer matrix

-Calculate position of sun in relation to building at any particular time

-Calculate vertical and horizontal surface solar radiation

-Calculate total input to conservatory and place in matrix

-Calculate surface and air temperatures and hence energy output

-Repeat for next hour

6.2.2 Weather Data

The weather data to be used for predicting the behaviour of the conservatory are that described in Section 3.2, i.e. data from Kew.

6.2.3 Position of the Sun and Intensity on the Surfaces

The precise position of the sun is calculated by the model using equations (3.3) and (3.4) and the intensity on the horizontal and vertical surfaces using equations (3.14) and (3.15).

6.2.4 Thermal Network Analysis

A three dimensional nodal arrangement was set up, consisting of seven nodes within the conservatory: one for each of the six surfaces and one for the air plus one each for the outside air, the inside air and the ground. The ground node was considered to be at the same temperature as the outside air (6.2.5). The number of nodes taken was for the sake of simplicity whilst ensuring good correlation with the Leicester conservatory. Combined with each of the nodes is a resistance running to each other node and in some case external resistances, inputs and capacitances. Fig(6.1)

Nodes 1, 2, 4 and 6 were on the glass, nodes 3 and 5 were on the wall and floor and node 7 the air.

Nodes 3 and 5 have a heat capacitance. The glass nodes 1, 2, 4 and 6 will have a very small capacitance which is assumed to be negligible and thus not introduced into the equations.

A balance for each of the nodes is done. There are two equations, those associated with nodes of no capacitance, and those with.

For nodes with no capacitance:

$$q_i = \frac{\Delta T_{i,j}}{R_{i,j}} + \frac{\Delta T_{i,k}}{R_{i,k}} + \frac{\Delta T_{i,l}}{R_{i,l}} + \frac{\Delta T_{i,M}}{R_{i,M}} + \frac{\Delta T_{i,N}}{R_{i,N}} + \frac{\Delta T_{i,o}}{R_{i,o}} \qquad (6.1)$$

which may be written as:

$$q_i = T_i\left(\frac{1}{R_{i,j}} + \frac{1}{R_{i,k}} + \frac{1}{R_{i,l}} + \frac{1}{R_{i,M}} + \frac{1}{R_{i,n}} + \frac{1}{R_{i,o}}\right) - \left(\frac{T_j}{R_{i,j}} + \frac{T_k}{R_{i,k}} + \frac{T_l}{R_{i,l}} + \frac{T_M}{R_{i,M}} + \frac{T_N}{R_{i,n}} + \frac{T_o}{R_{i,o}}\right) \qquad (6.2)$$

For the node containing the capacitances, the temperature of the node is predicted by using its previous temperature and the future state of the neighbouring nodes. Since many of the nodes are not dependant upon their previous state for their calculation, the calculation is simplified.

$$T_i + dt\frac{q_i}{C_i} = T_i' + \frac{(T_i'-T_j)dt}{R_{i,j}C_i} + \frac{(T_i'-T_k)dt}{R_{i,k}C_i} + \frac{(T_i'-T_l)dt}{R_{i,l}C_i} + \frac{(T_i'-T_M)dt}{R_{i,M}C_i} + \frac{(T_i'-T_n)dt}{R_{i,n}C_i} + \frac{(T_i'-T_o)dt}{R_{i,o}C_i} \qquad (6.3)$$

Simplifying equation (6.3)

$$T_i + dt\frac{q_i}{C_i} = T_i'\left(1 + \frac{dt}{R_{i,j}C_i} + \frac{dt}{R_{i,k}C_i} + \frac{dt}{R_{i,l}C_i} + \frac{dt}{R_{i,M}C_i} + \frac{dt}{R_{i,n}C_i} + \frac{dt}{R_{i,o}C_i}\right) - \left(\frac{T_j\,dt}{R_{i,j}C_i} + \frac{T_k\,dt}{R_{i,k}C_i} + \frac{T_l\,dt}{R_{i,l}C_i} + \frac{T_M\,dt}{R_{i,M}C_i} + \frac{T_n\,dt}{R_{i,n}C_i} + \frac{T_o\,dt}{R_{i,o}C_i}\right) \qquad (6.4)$$

with the equations being in the form of (6.2) and (6.4), they may be set out in the form:

$$AX = B \qquad (6.5)$$

where the matrix A contains the coefficients of the unknown temperaures and B contains the inputs on the left of the equation.

This matrix is solved by the NAg routine FO4AEF which calculates the accurate solution of real linear equations with multiple right hand side by Crout's factorisation method. Although the model does not warrant the use of the accurate method, the approximate method used by the routine F04ADF did not appear to be any faster in C.P.U. time.

6.2.5 Heat Transfer Coefficients

Of the utmost importance in an accurate simulation is the calculation of the heat transfer coefficients. Many of these were taken from the C.I.B.S.E. guide (1981) and from Billington (1967).

For laminar flow

From a vertical surface $Gr < 10^8$

$$\overline{Nu} = 0.75 \times 0.36 \times Gr^{0.25} \tag{6.6}$$

From a horizontal surface $1.4 \times 10^5 < Gr < 3 \times 10^7$

$$\overline{h}_h = 1.4\ (dT/L)^{0.25} \tag{6.7}$$

where dT = temperature difference / K

For turbulent flow $Gr > 10^9$

From a vertical surface

$$Nu = 0.1(Pr\ Gr)^{0.33} \tag{6.8}$$

From a horizontal surface

$$h = 1.7\ dT^{0.33} \tag{6.9}$$

where $Gr = (9.8 \times \rho^2 \times L^3 dT)/(278 \times \mu^2)$ (6.10)

and $\overline{Nu} = hL/k$ (6.11)

and dT = temperature differnce / K

and $\overline{Nu} = \frac{hd}{k}$ (6.11)

Pr in equation (6.8) may be taken as 0.7 for air.

The heat capacitance of the materials was taken from the CIBSE guide (1971) at 800 J/kgK for the wall and 1000 J/kgK for the concrete floor. An overall U-Value of 5.7 W/m^2K was taken for the glass to include the wood-frame. The overall admittance was 0.76. For the purposes of modelling the Leicester conservatory, the resistance of the partition wall was as described in 5.2.3. Air infiltration was taken from Table A4.12 of the CIBSE guide (1981) at a half of an air-change per hour. This was rounded to 0.005 m^3/s. For later modelling the precise air change rate will be known.

The heat loss from the floor was calculated following the method described in A3 of the CIBSE guide (1981). An overall U-Value of 1.2 W/m^2K to the outside air was used. This assumes an average earth conductance of 1.4 W/mK.

The radiative heat transfer coefficient is given by

$$h = 5.8 \times \mathcal{F} \times F \qquad (6.12)$$

where:

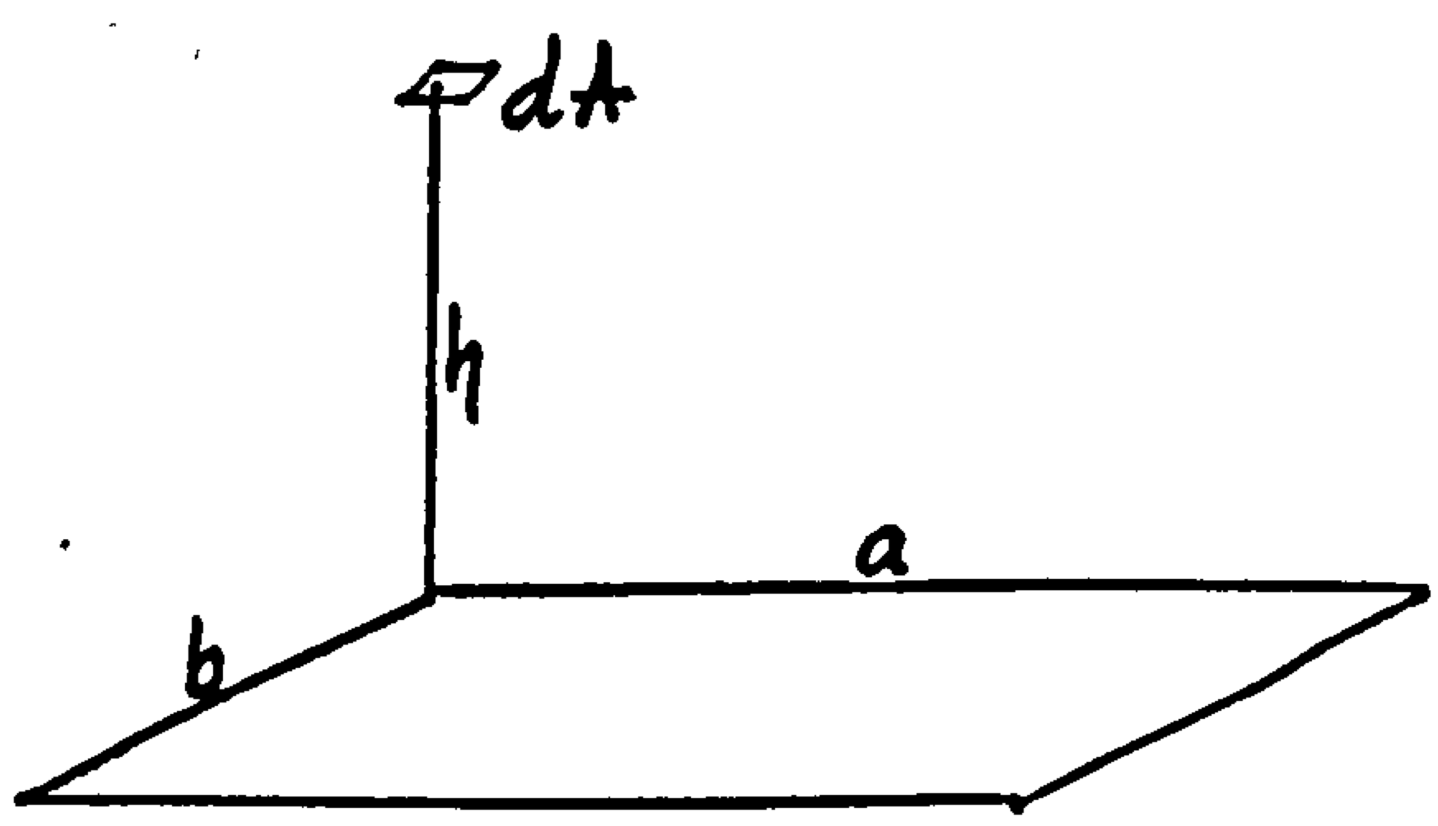
$$\mathcal{F} = \left[\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right]^{-1}$$

It was found that the configuration factor F, was particularly important in the simulation of the model, and whilst single calculations between parallel surfaces are easily undertaken, an attempt was made to find a general solution for the configuraton factor, given any angle and distance between surfaces.

6.2.6 Configuration factors

The general solution for configuration factors is in FORTRAN program SHAPE04.

Initially a small area parallel to a large plate of finite area a by b is considered.

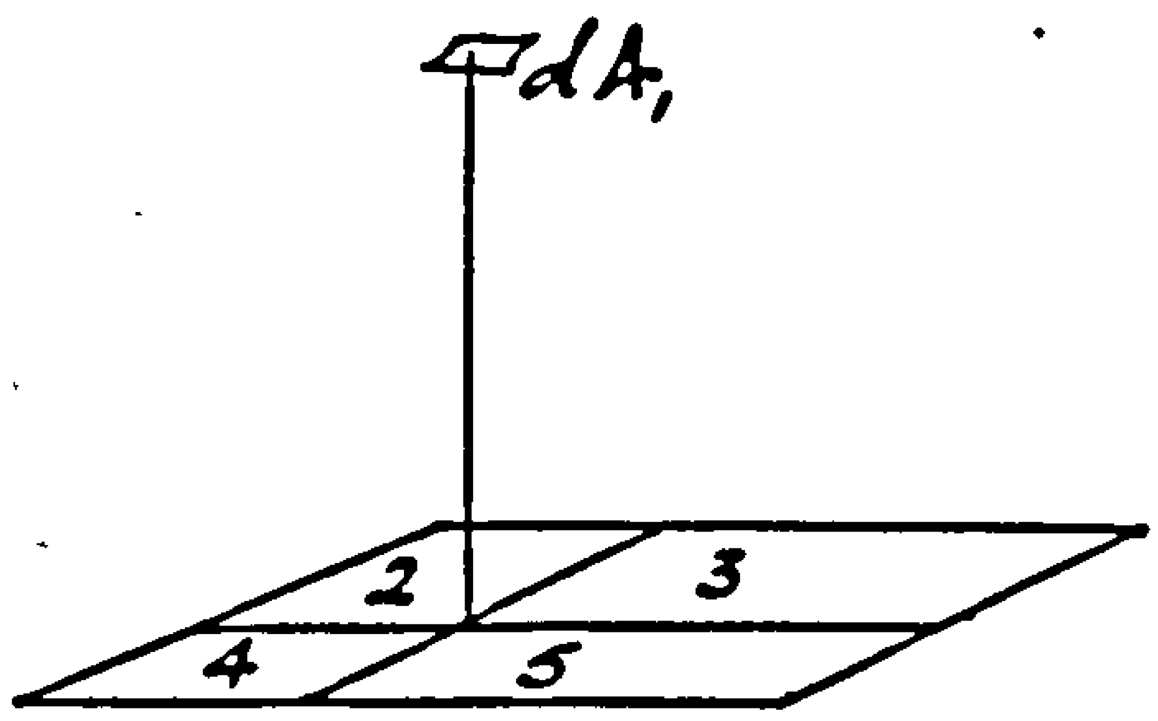


From Eckert and Drake (1972)

$$F_{p1,2} = \frac{1}{2\pi}\left(\frac{a}{(a^2+h^2)^{1/2}}\tan^{-1}\frac{b}{(a^2+h^2)^{1/2}} + \frac{b}{(b^2+h^2)^{1/2}}\tan^{-1}\frac{a}{(b^2+h^2)^{1/2}}\right) \qquad (6.13)$$

From equation (6.13) it is possible to calculate the configuration factor F but only when dA is over a corner.

but



$$F_{p1-(2,3,4,5)} = F_{p1-2} + F_{p1-3} + F_{p1-4} + F_{p1-5} \qquad (6.14)$$

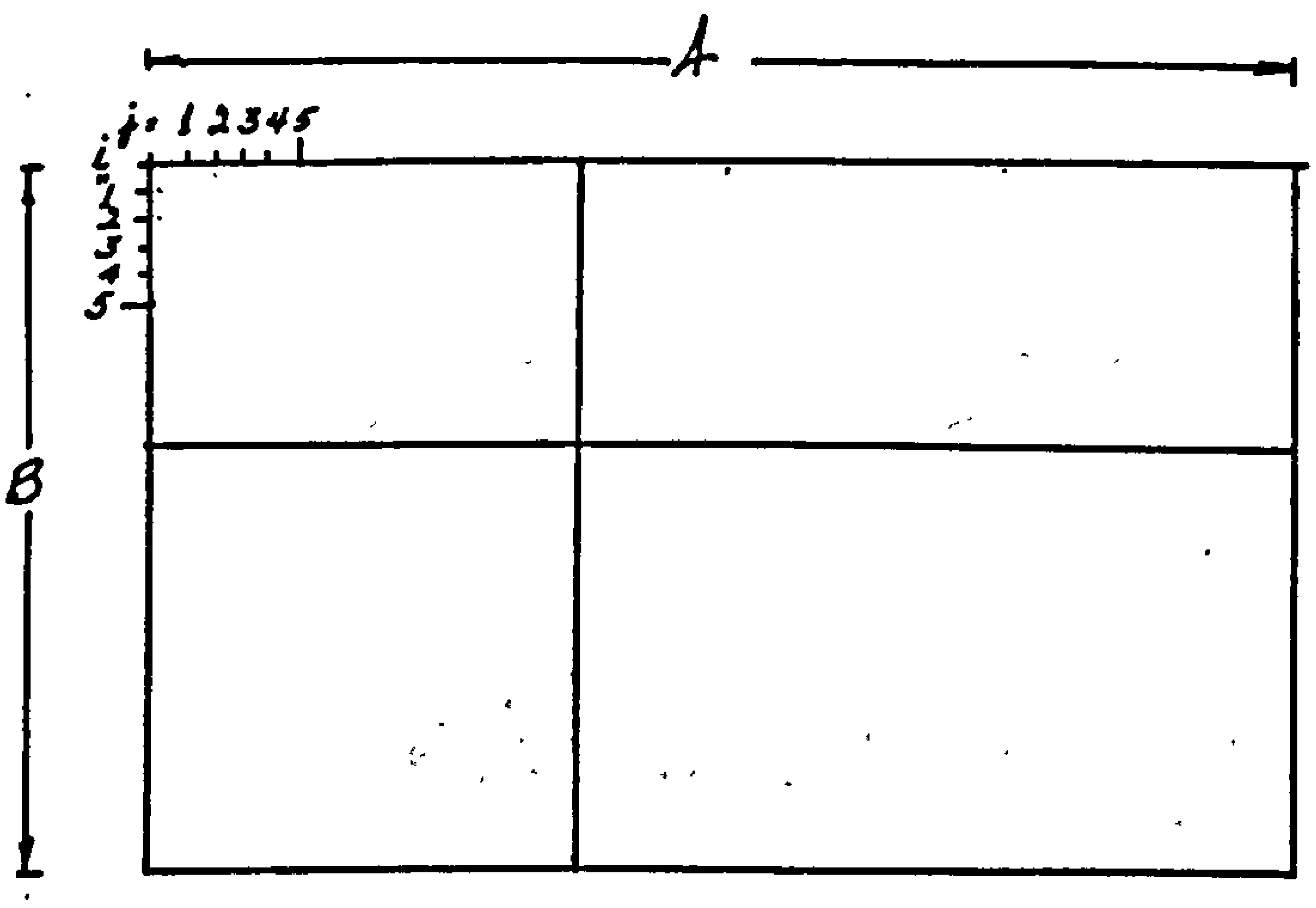
So that the overall values for F may be calculated using (3.23). However new values for A an B will be needed. These will be known as $A_2, A_3, A_4 \ldots$ and $B_2, B_3 \ldots$.

To calculate an overall configuration factor for two surfaces A by B, the upper surface will be divided into many small areas dA . A matrix of n x n will be constructed.

The area between each square will be dA and dB

$$dA = A/(n-1) \quad (6.15)$$

$$dB = B/(n-1) \quad (6.16)$$



The dimensions are:

$$A2 = dA(i-1) \qquad B2 = dB(j-1) \quad (6.17)$$

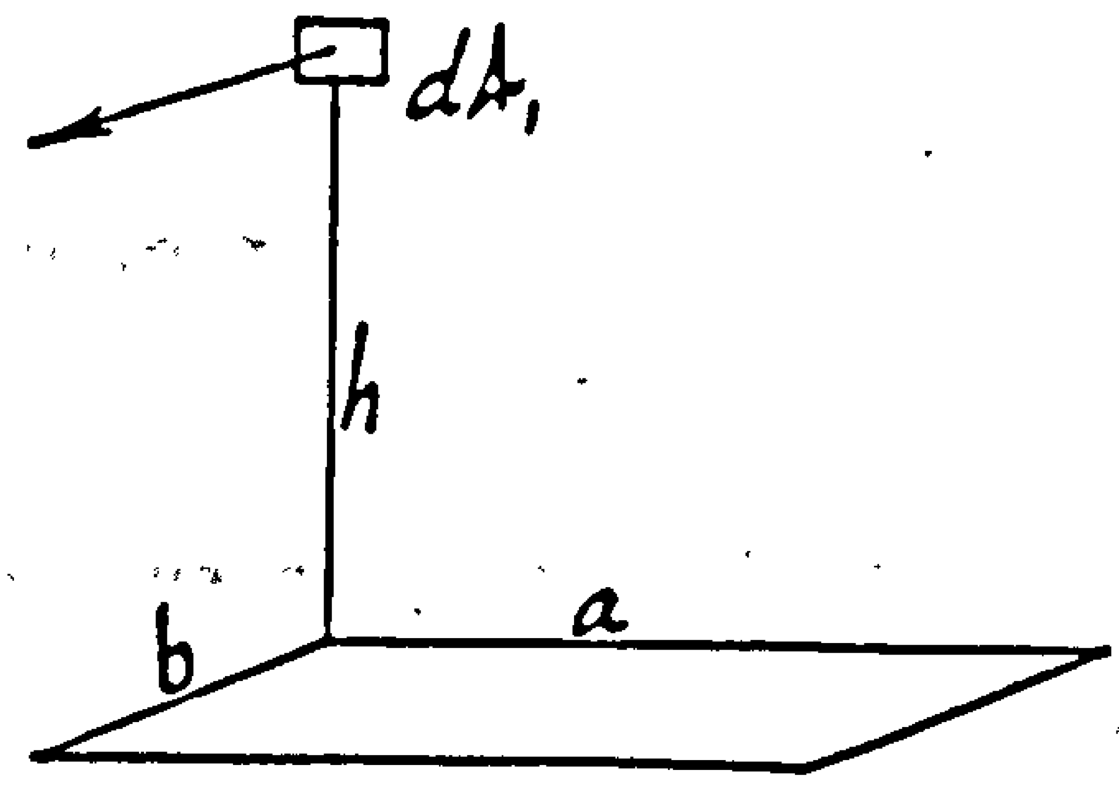
$$A3 = A-(dA(i-1)) \qquad B3 = dB(j-1) \quad (6.18)$$

$$A4 = A-(dA(i-1)) \qquad B4 = B-(dB(j-1)) \quad (6.19)$$

$$A5 = dA(i-1) \qquad B5 = B-(dB(j-1)) \quad (6.20)$$

(6.17),(6.18),(6.19) and (6.20) give the dimensions of each square. Four configuration factors which, added together, give the overall value. Because the value is that of a point representing an area of dA, the values must be divided by four at the corners and by two on the sides. All the values may now be averaged to give F .

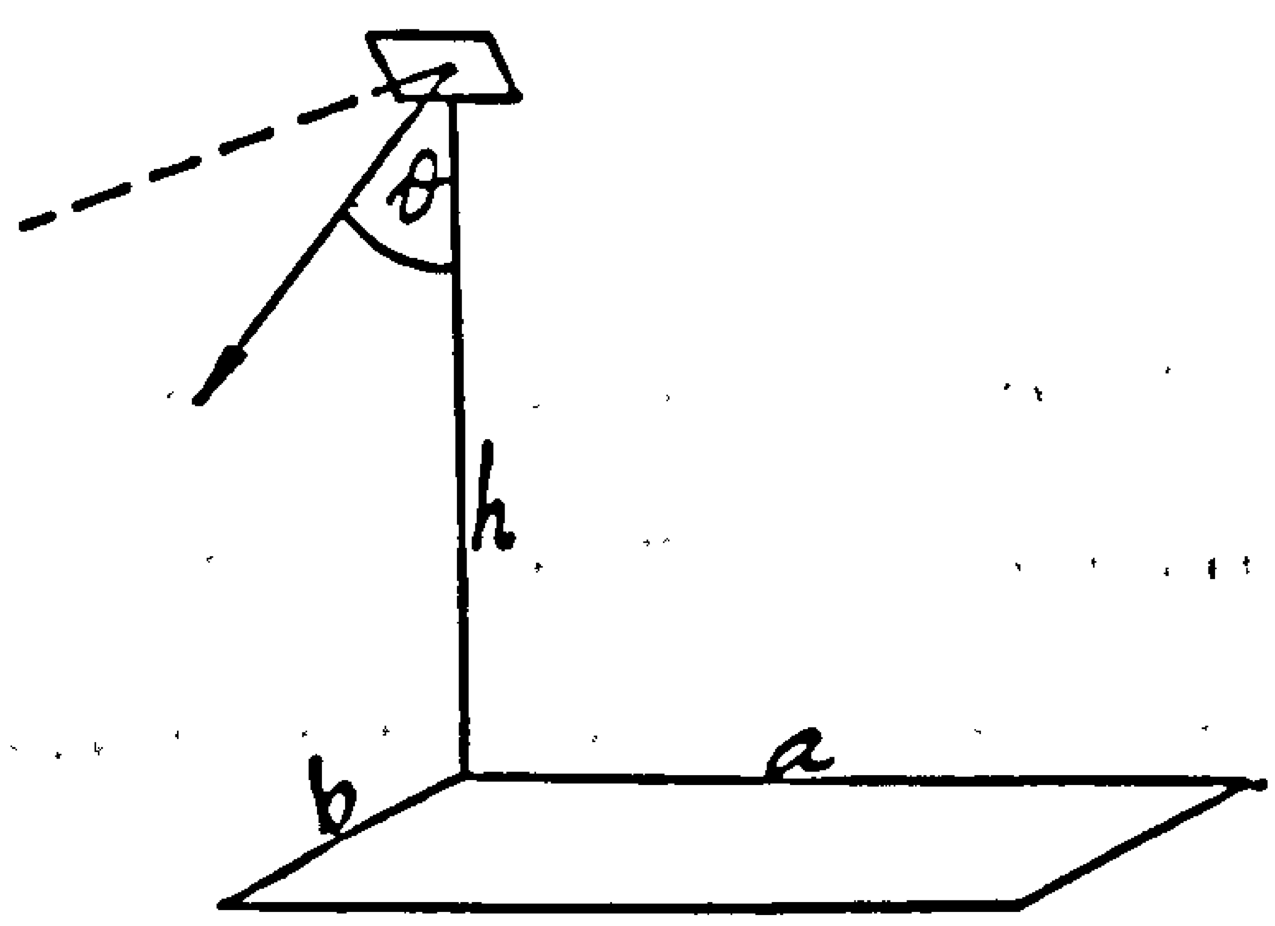
A similar procedure may be followed for the perpendicular surface.



$$F_{n1-2} = \frac{1}{2\pi}\left(\tan^{-1}\frac{b}{h} - \frac{h}{(a^2+b^2)^{1/2}}\tan^{-1}\frac{b}{(a^2+b^2)^{1/2}}\right) \tag{6.21}$$

Hence for any two surfaces, an overall value for F and F is calculated. Generally, little difference was found if the value of n was increased above 20, hence a 20 x 20 matrix was used.

To calculate the value for a sloping surface, a simple equation(6.22) is used



where $\phi = \theta - 90^{\circ}$

$$F_{\phi 1-2} = F_{p1-2}\sin\phi + F_{n1-2}\cos\phi \tag{6.22}$$

6.3 Comparison of Model with Recorded Measurements

6.3.1 Adjustments to model

For simulating the behaviour of the conservatory at Leicester, it was not necessary for the model to calculate the position of the sun and the intensity on the horizontal and vertical surfaces, since readings were taken from horizontal and vertical solarimeters giving observed data for these components for each scan. Similarly, the orientation of the conservatory was not required.

The conservatory, being of traditional construction, had much timber framework. This was estimated to be about 20 % of the overall external surface. Since this was evenly spread over the whole surface it was asssumed to affect the solar admittance similarly for all solar angles and hence the admittance was reduced accordingly. Although this is not precisely true, the differences are negligible at this level of accuracy.

A portion of the conservatory contained a trellis table which covered about one third of the floor. The floor area considered to be reradiating heat was therfore taken to be two thirds of the total floor.

The model simulates the behaviour of the conservatory at hourly intervals whilst the recorded readings were taken at twelve minute intervals, hence the input values required by the model such as the solar radiation and the outside air temperature had to be altered to hourly values.

6.3.2 Comparison of Results

The computer model SUNSPACE was run to simulate the behaviour of each of the days for which data were available.

A sample of the results are shown in Figs(6.2)-(6.8) for days 51-59 corresponding to the 20th to 26th of February 1985. The upper graph shows the outside air temperature and solar input on the horizontal and vertical aggregated to hourly values. The lower graph shows the actual conservatory temperature and the predicted hourly conservatory temperature.

The model follows fairly closely the rise and fall of the conservatory temperature.

The expected heat gain from the conservatory by conduction and convection through the wall was calculated for each day. Figs(6.10)-(6.15) summarise these results daily for two weeks for the days recorded.

Where incomplete data is shown this is due to a fault in the logging equipment where some readings were not taken or corrupted, or that the recording medium, paper tape or cassette tape run out unexpectantly. Under these circumstances the model was initialised with the conservatory air temperatures set at the outside air temperature and the wall temperatures set at the logger room temperature. This means that the first few hours of the model or that particular day are unreliable.

6.3.4 Inaccuracy

The model is inaccurate since it works only hourly and hence does not take account of short periods of strong sunlight. It is for this reason that the maximum recorded daily temperature is generally higher than the predicted maximum temperature. Similarly this leads to smaller predicted swings in the conservatory air temperatures than were monitored. The model is poor at predicting the behaviour when the outside air temperature is high but there is little or no sunshine, typical of some days in autumn. Then the predicted output is sometimes as much as 50% incorrect because the conservatory air temperature is close to the outside air temperature. When there is a large external air temperature swing such as 5-10 K in two hours, the model can take three to four hours before it is in phase with predicted values since it is slower to react as it works hourly.

These inaccuracies generally occur at a time when the solar input is low and the measured output is low. The difference over two weeks is rarely above 20 %, generally much lower.

The model would give better results if it worked at a greater frequency than once an hour but since such weather data are not available, this is not practical.

6.4 Summary and Conclusions

6.4.1 A computer model was written to simulate the behaviour of a conservatory of any size, orientation or latitude.

6.4.2 The model was based on a nodal network about the conservatory and predicts the behaviour hourly.

6.4.3 A routine was written to calculate the precise shape factors.

6.4.4 The model was written to use standard meteorological data from Kew.

6.4.5 Comparison between predicted behaviour and actual behaviour of the Leicester conservatory was good.

6.4.6 Inaccuracies occured under very rapidly changing external air temperature and because the model only worked hourly, its maximum practical frequency.

6.4.7 The model may be assumed to be at least 80 % accurate.

6.4.8 The model may be used by any designer to give a predicted behaviour of any conservatory. The pertinent data of the conservatory are contained on the file: SPACE DATA. The designer need only enter his/her particular data to give an hour by hour simulation. Similarly, conservatory data may be varied to investigate the performances given varying circumstances such as orientation or shape.

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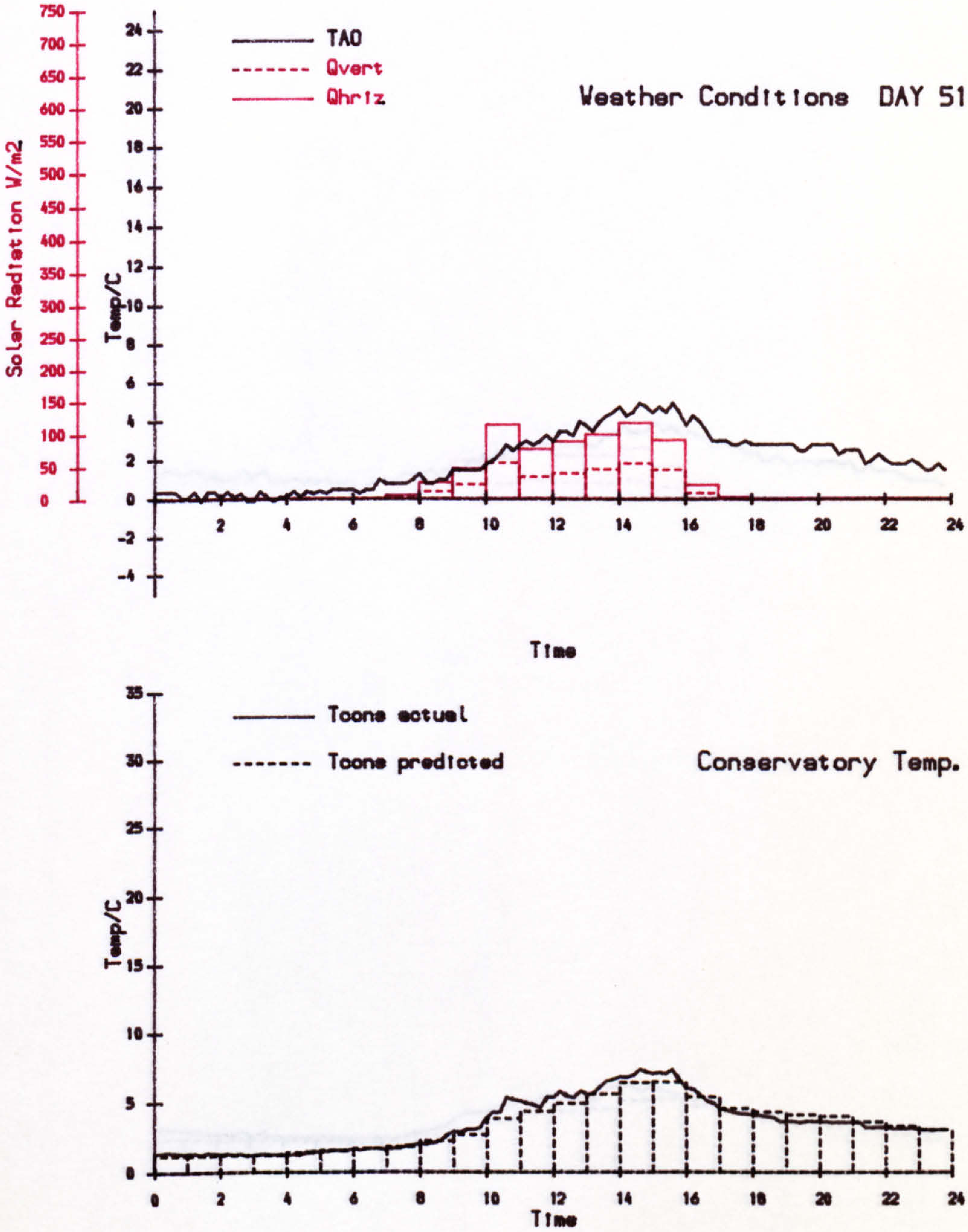
SCHEMATIC OUTLINE OF CONSERVATORY HEAT TRANSFER COEFFICIENTS

Figure (6.1)

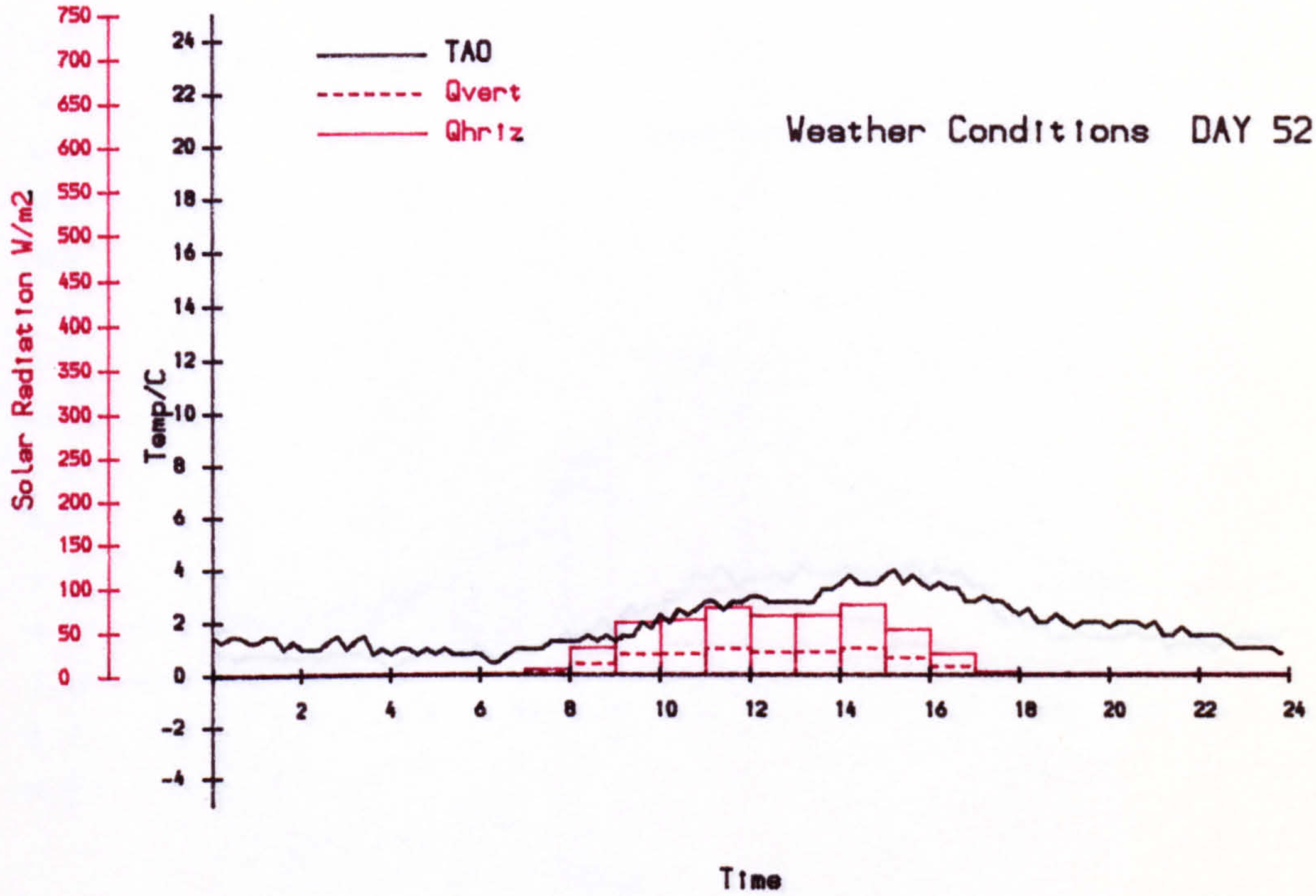


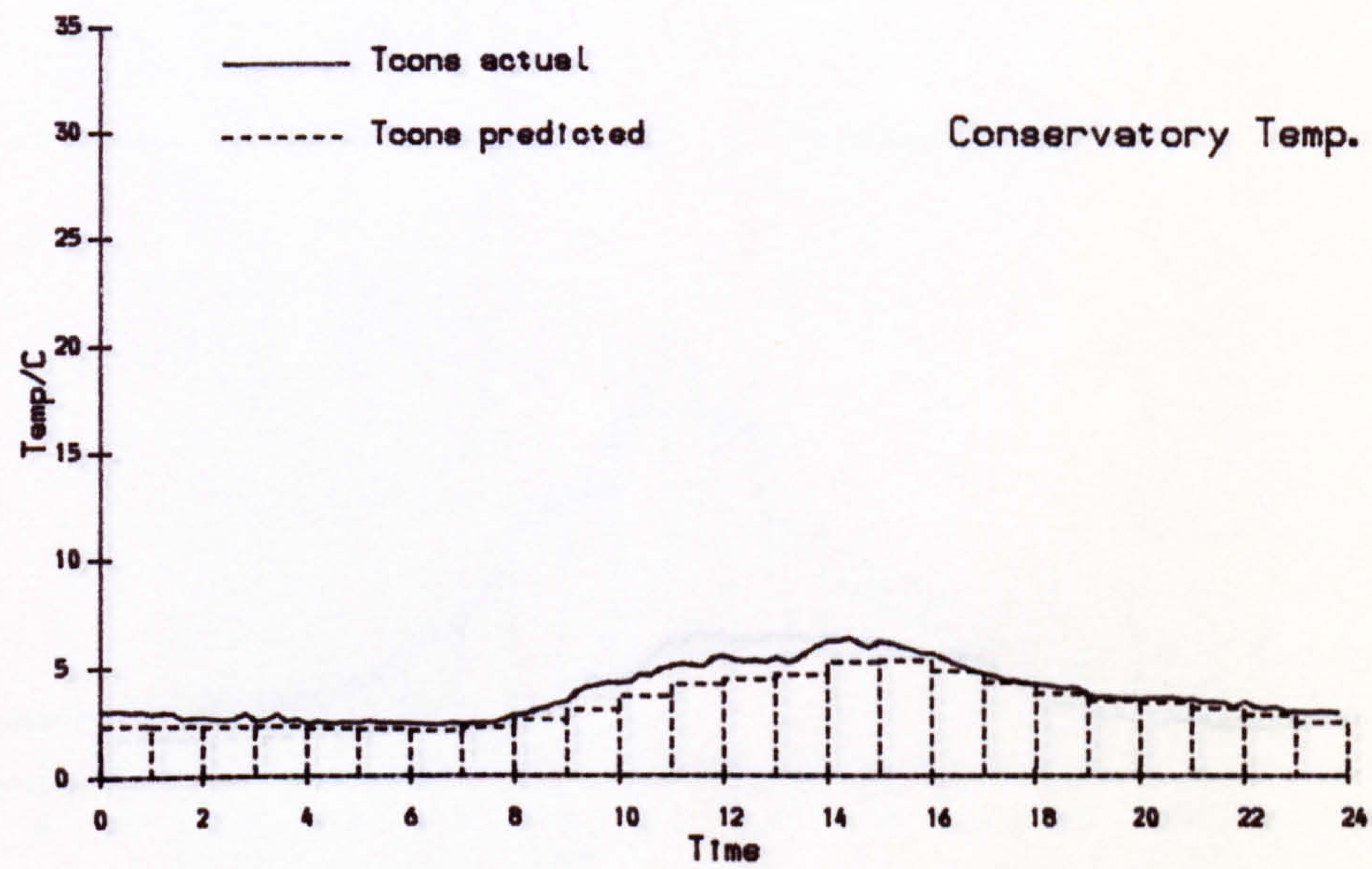
TAO swing :	5.0 K	Standard difference :	0.37 K
Tcons swing, measured :	6.2 K	Percentage error, Qout :	
Tcons swing, predicted :	5.3 K	Measured solar input is shown	
Qwall, measured	: 249.9 kJ	as an average hourly value	
Qwall, predicted	: 199.2 kJ	for the purpose of the model	20.3 %

Actual & Modelled Conservatory Temperatures

Compares the modeled resuls to the real results

Figure (6.2)



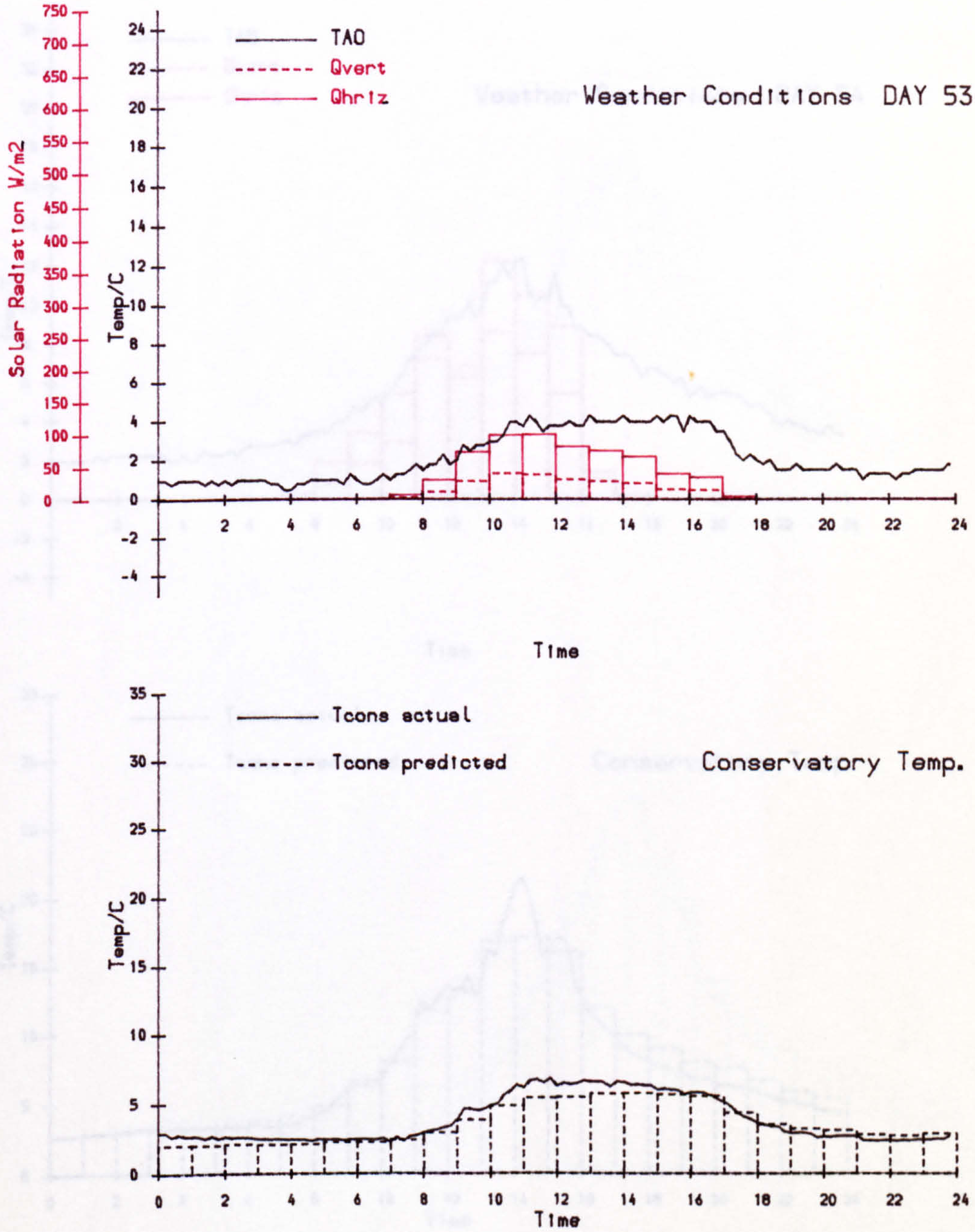


TAO swing :	3.5 K	Standard difference :	0.56 K
Tcons swing, measured :	4.0 K	Percentage error, Qout :	
Tcons swing, predicted :	3.2 K	Measured solar input is shown	
Qwall, measured	: 78.4 kJ	as an average hourly value	
Qwall, predicted	: 0.0 kJ	for the purpose of the model 0.0 %	

Actual & Modelled Conservatory Temperatures

Compares the modeled resuls to the real results

Figure (6.3)

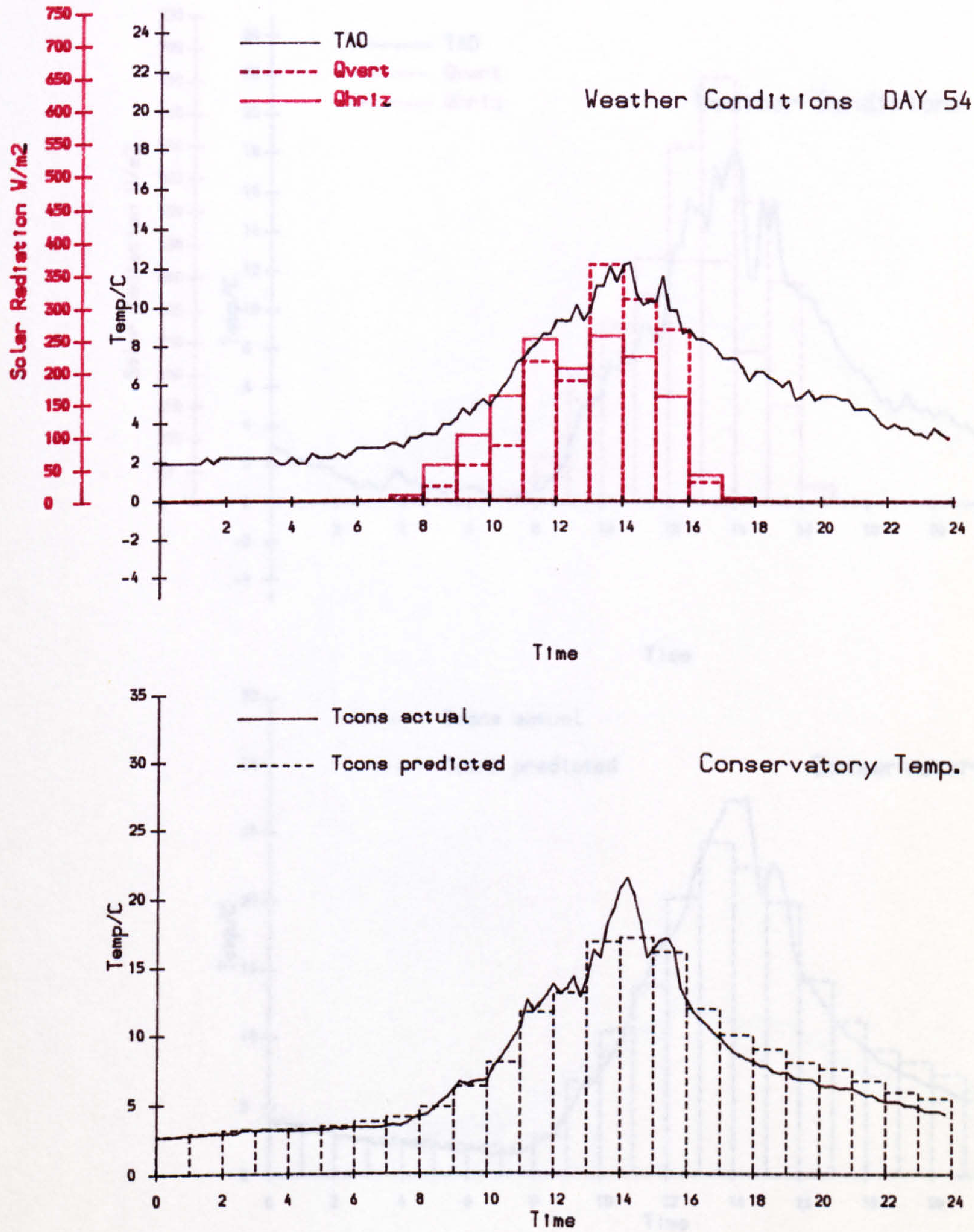


TAO swing :	3.8 K	Standard difference :	0.52 K
Tcons swing, measured :	4.6 K	Percentage error, Qout :	
Tcons swing, predicted :	3.8 K	Measured solar input is shown	
Qwall, measured	: 61.0 kJ	as an average hourly value	
Qwall, predicted	: 0.0 kJ	for the purpose of the model	0.0 %

Actual & Modelled Conservatory Temperatures

Compares the modeled resuls to the real results

Figure (6.4)

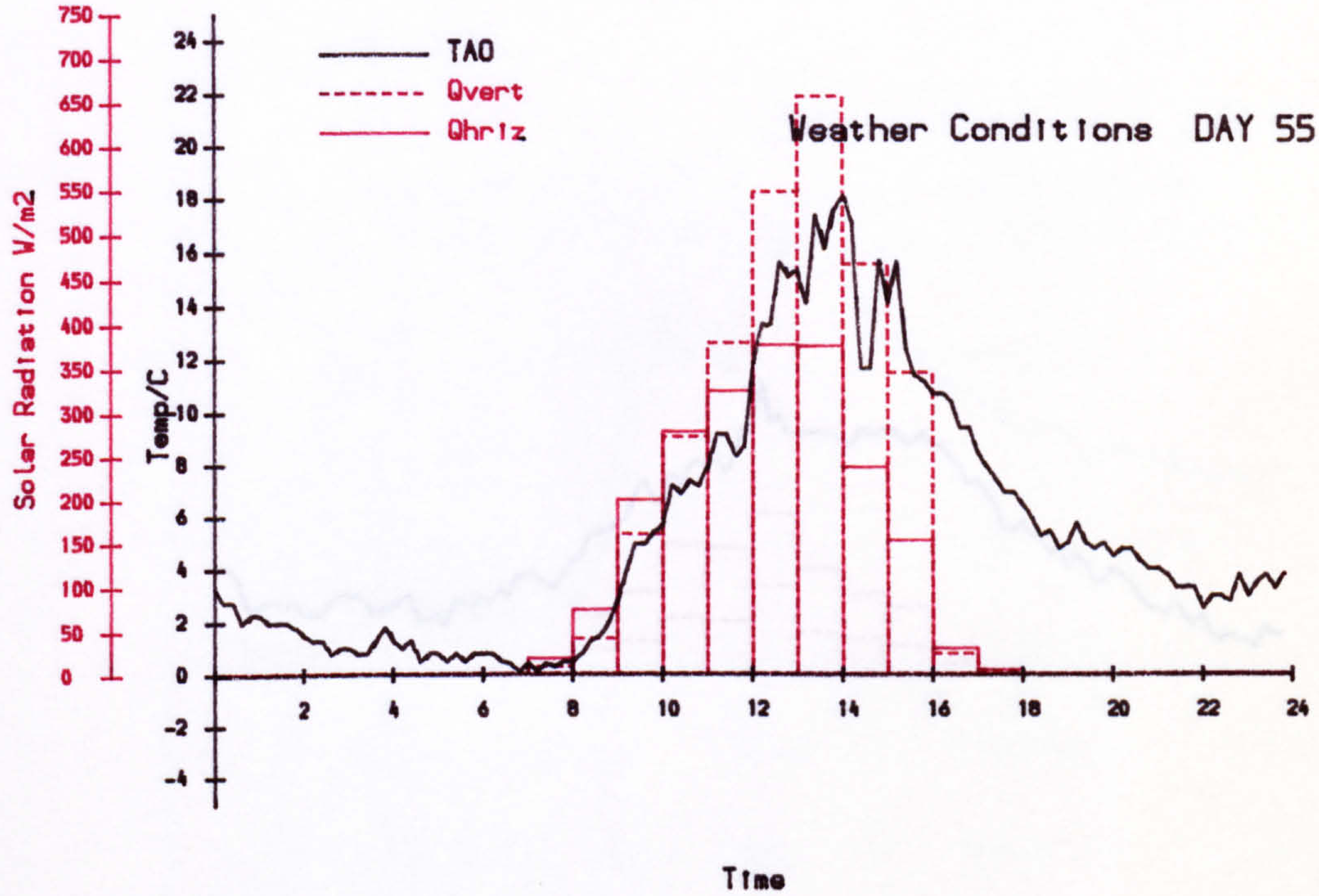


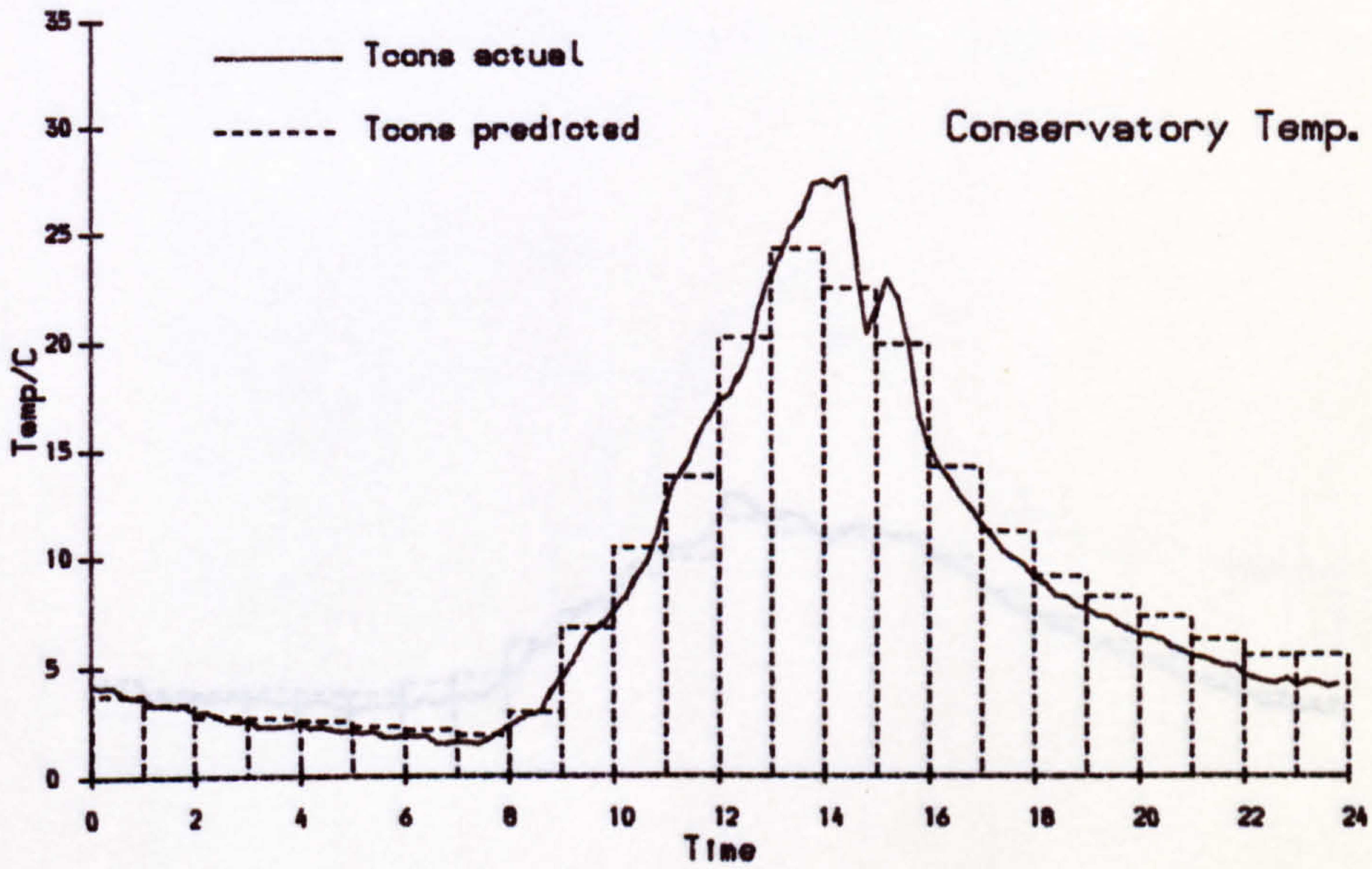
TAO swing : 10.4 K	Standard difference : 0.80 K
Tcons swing, measured : 18.7 K	Percentage error, Qout : 1.2 %
Tcons swing, predicted : 14.4 K	Measured solar input is shown
Qwall, measured : 507.5 kJ	as an average hourly value
Qwall, predicted : 513.5 kJ	for the purpose of the model

Actual & Modelled Conservatory Temperatures

Compares the modeled resuls to the real results

Figure (6.5)



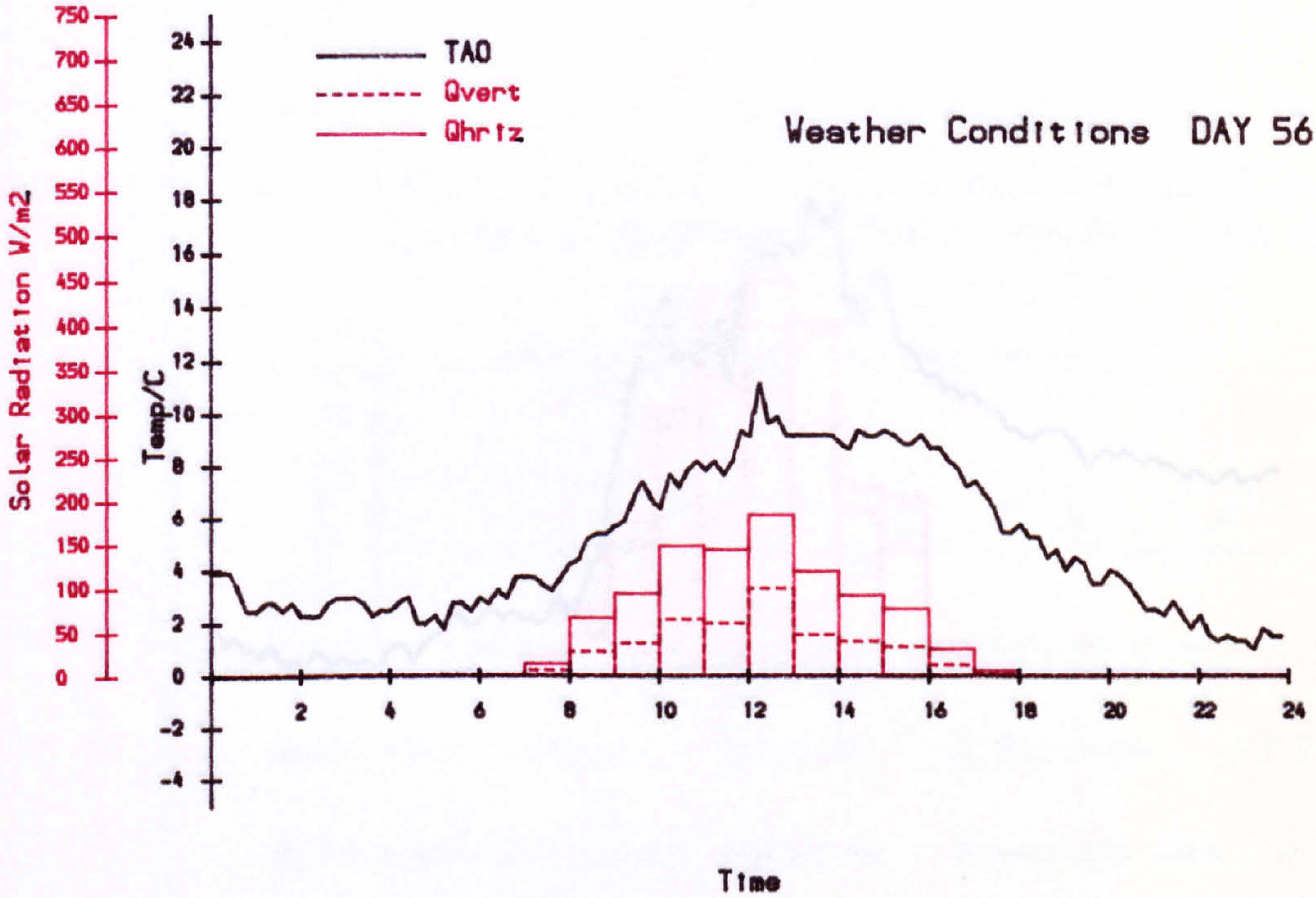


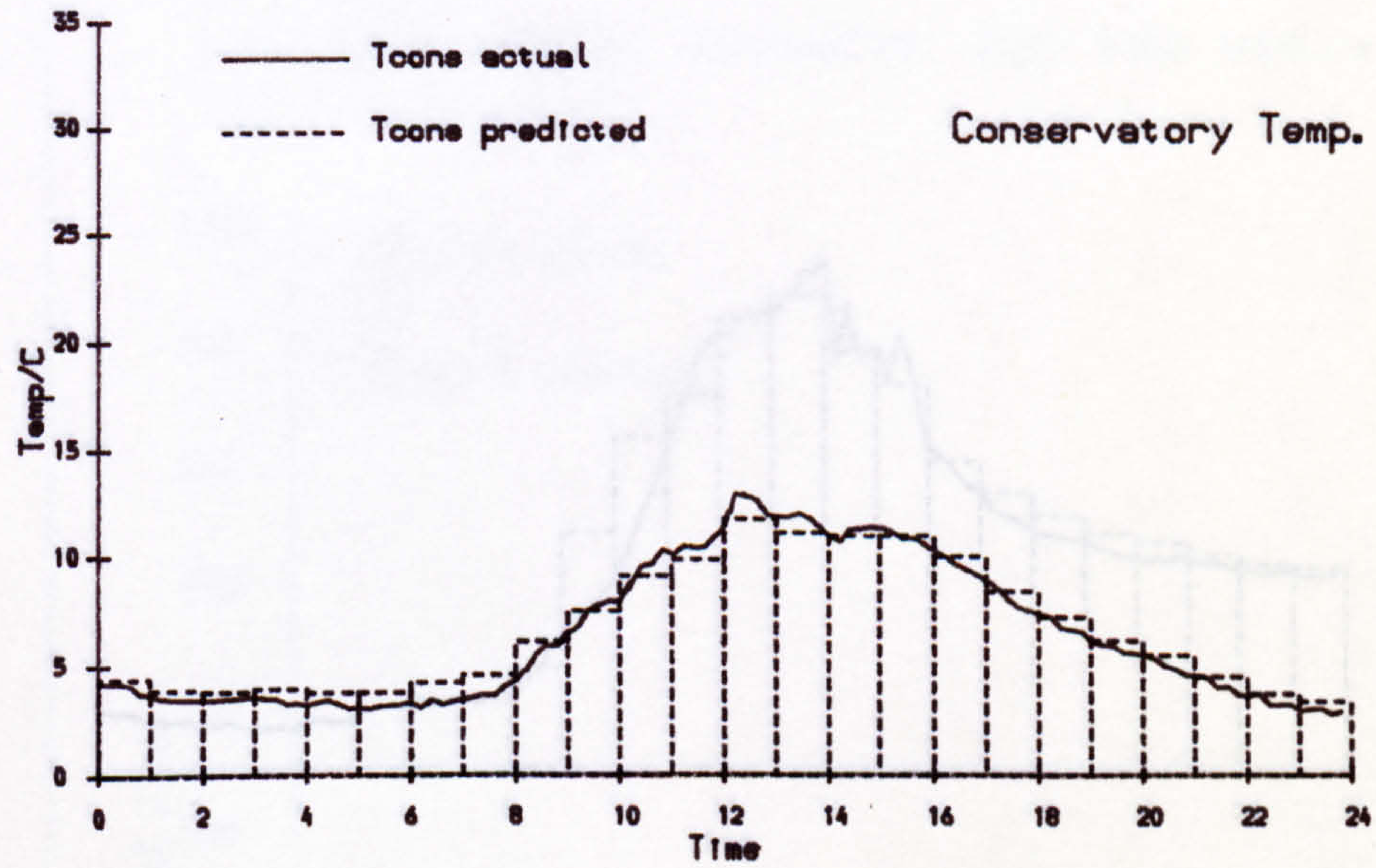
TAO swing :	18.0 K	Standard difference :	1.00 K
Tcons swing, measured :	26.2 K	Percentage error, Qout :	
Tcons swing, predicted :	22.4 K	Measured solar input is shown	
Qwall, measured	: 936.6 kJ	as an average hourly value	
Qwall, predicted	: 952.3 kJ	for the purpose of the model 1.7 %	

Actual & Modelled Conservatory Temperatures

Compares the modeled resuls to the real results

Figure (6.6)



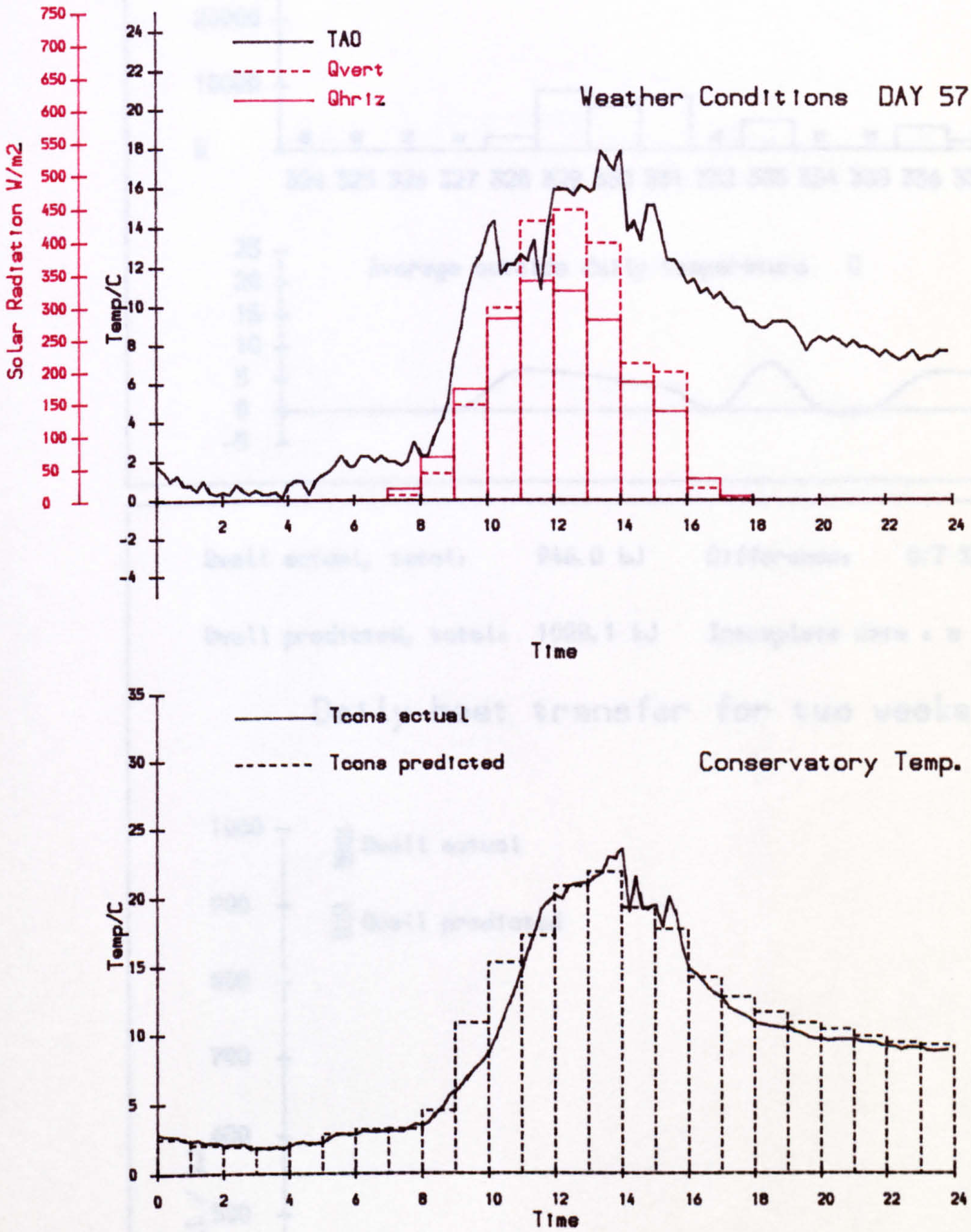


TAO swing :	10.2 K	Standard difference :	0.51 K
Tcons swing, measured :	10.2 K	Percentage error, Qout :	
Tcons swing, predicted :	8.4 K	Measured solar input is shown	
Qwall, measured	: 125.2 kJ	as an average hourly value	
Qwall, predicted	: 114.6 kJ	for the purpose of the model	8.5 %

Actual & Modelled Conservatory Temperatures

Compares the modeled resuls to the real results

Figure (6.7)

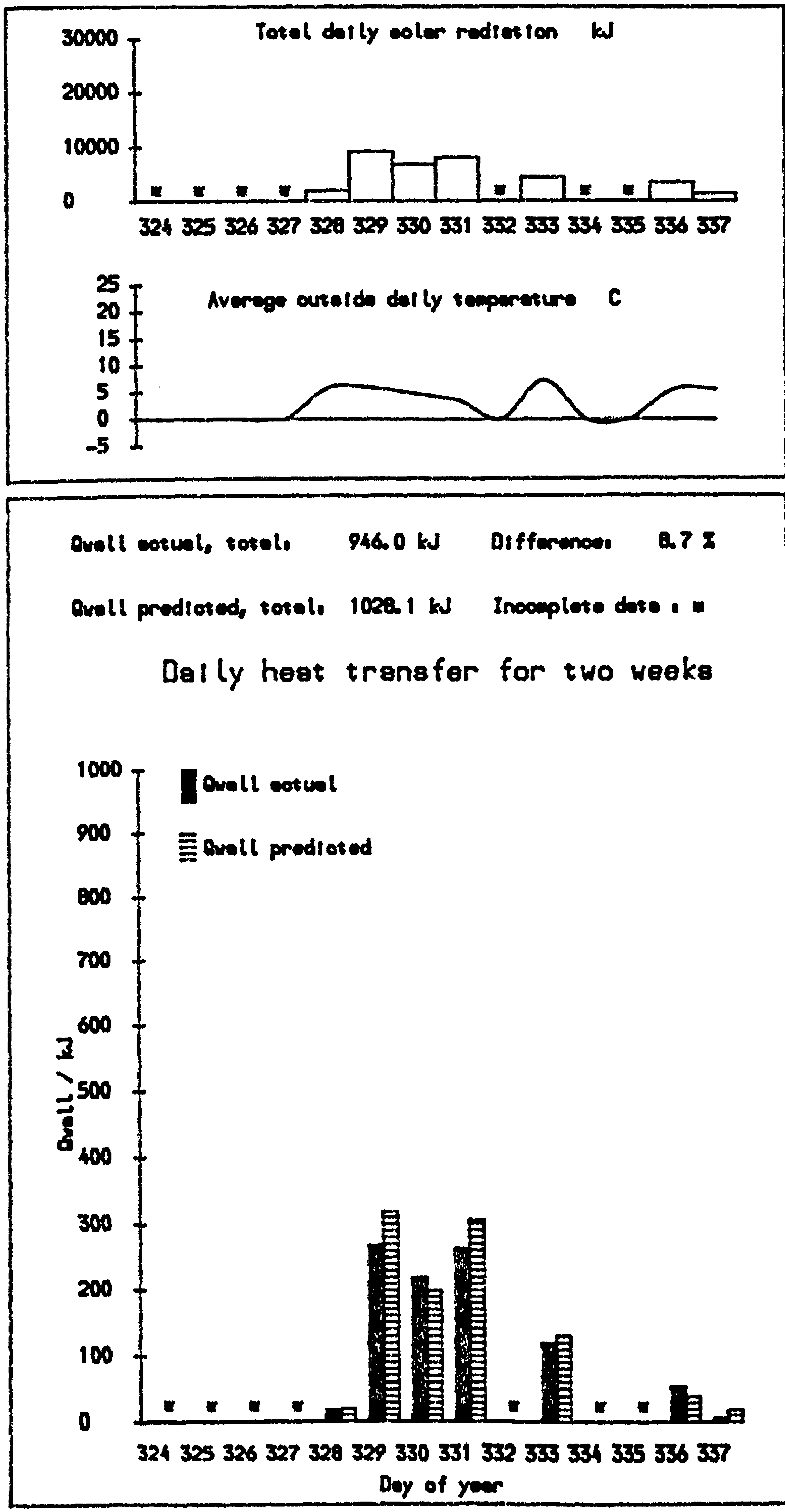


TAO swing :	17.8 K	Standard difference :	1.30 K
Tcons swing, measured :	21.8 K	Percentage error, Qout :	
Tcons swing, predicted :	20.0 K	Measured solar input is shown	
Qwall, measured	: 735.4 kJ	as an average hourly value	
Qwall, predicted	: 940.6 kJ	for the purpose of the model	27.9 %

Actual & Modelled Conservatory Temperatures

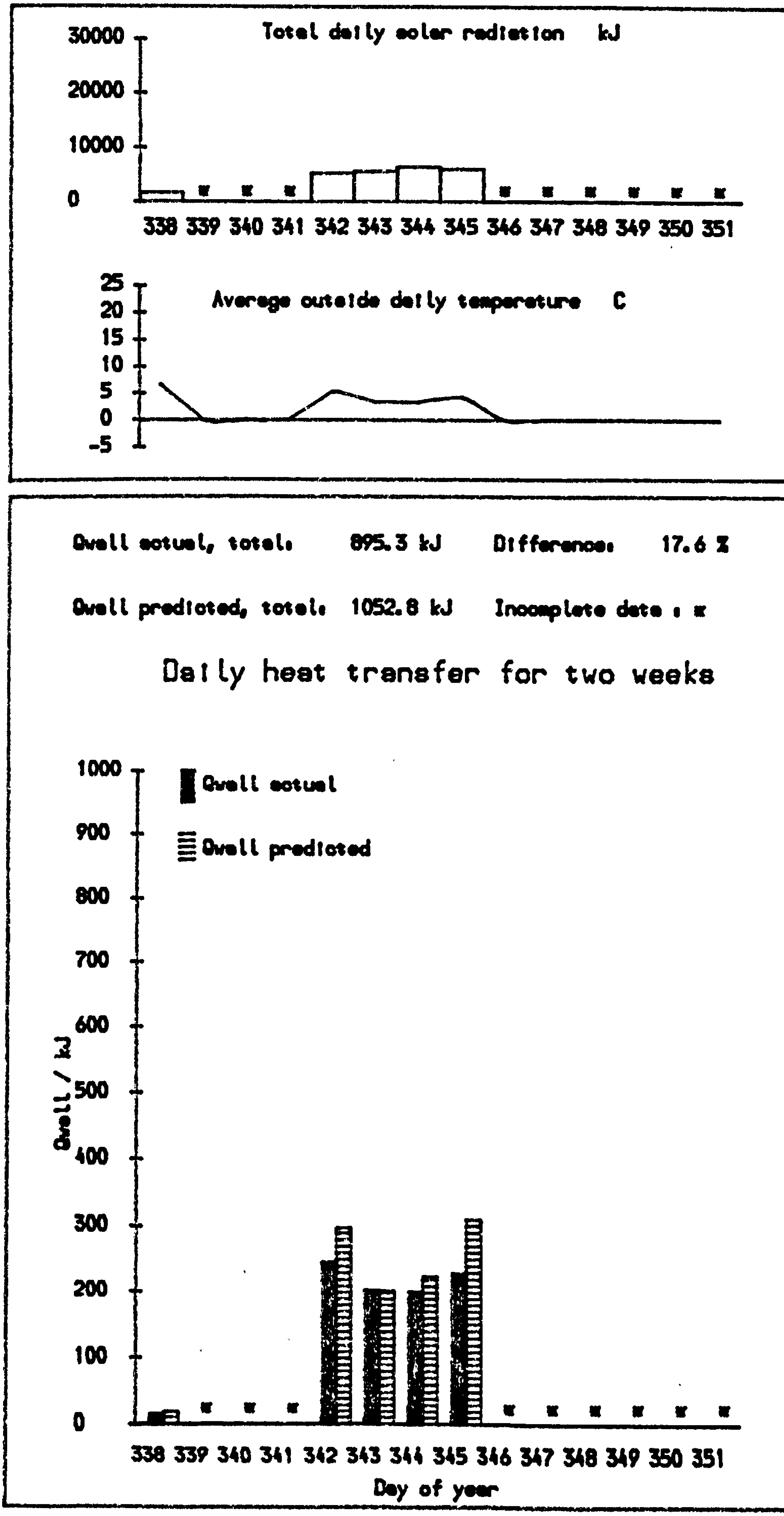
Compares the modeled resuls to the real results

Figure (6.8)



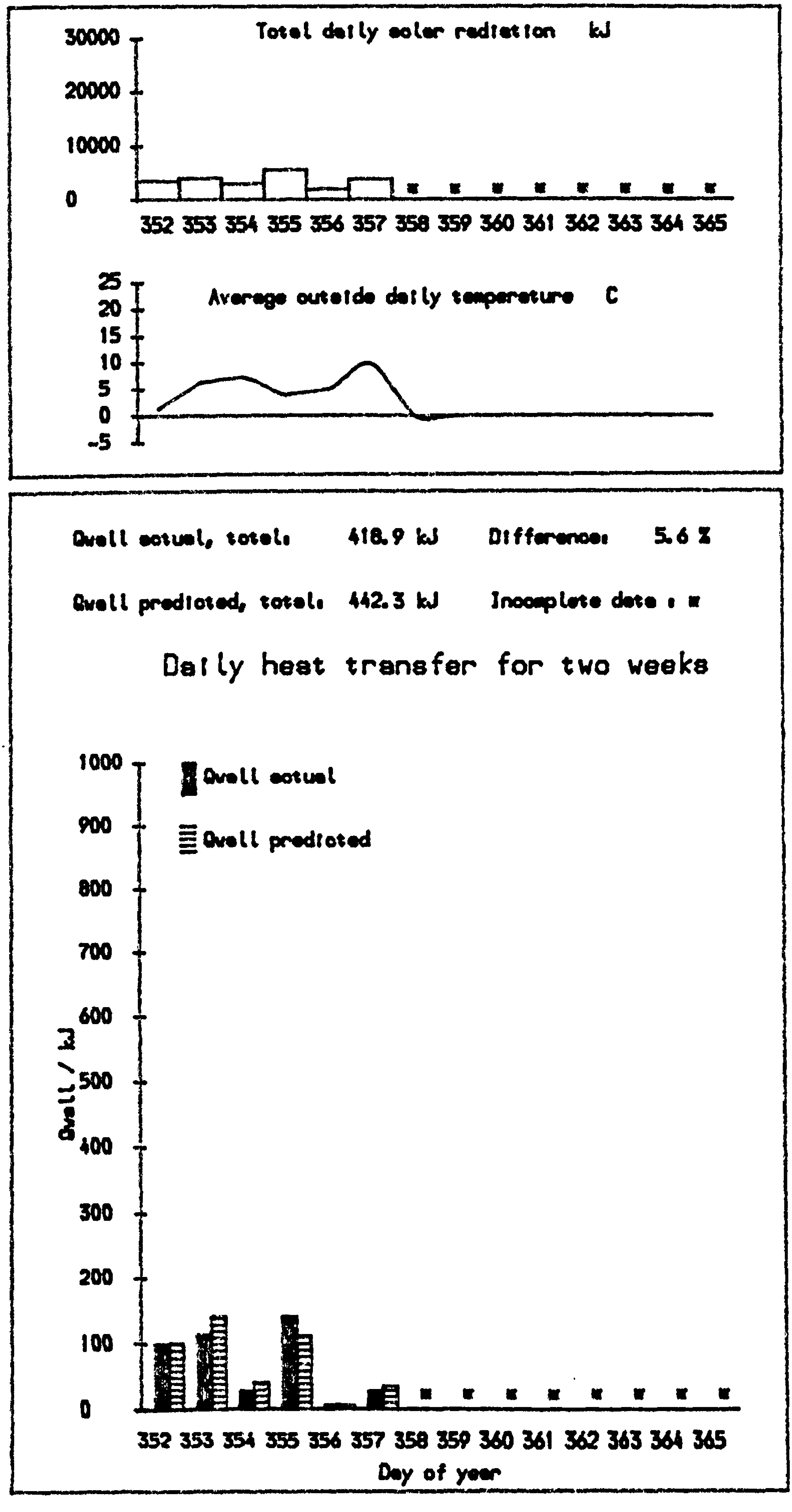
Comparison of actual conservatory output with predicted output

Figure (6.9)



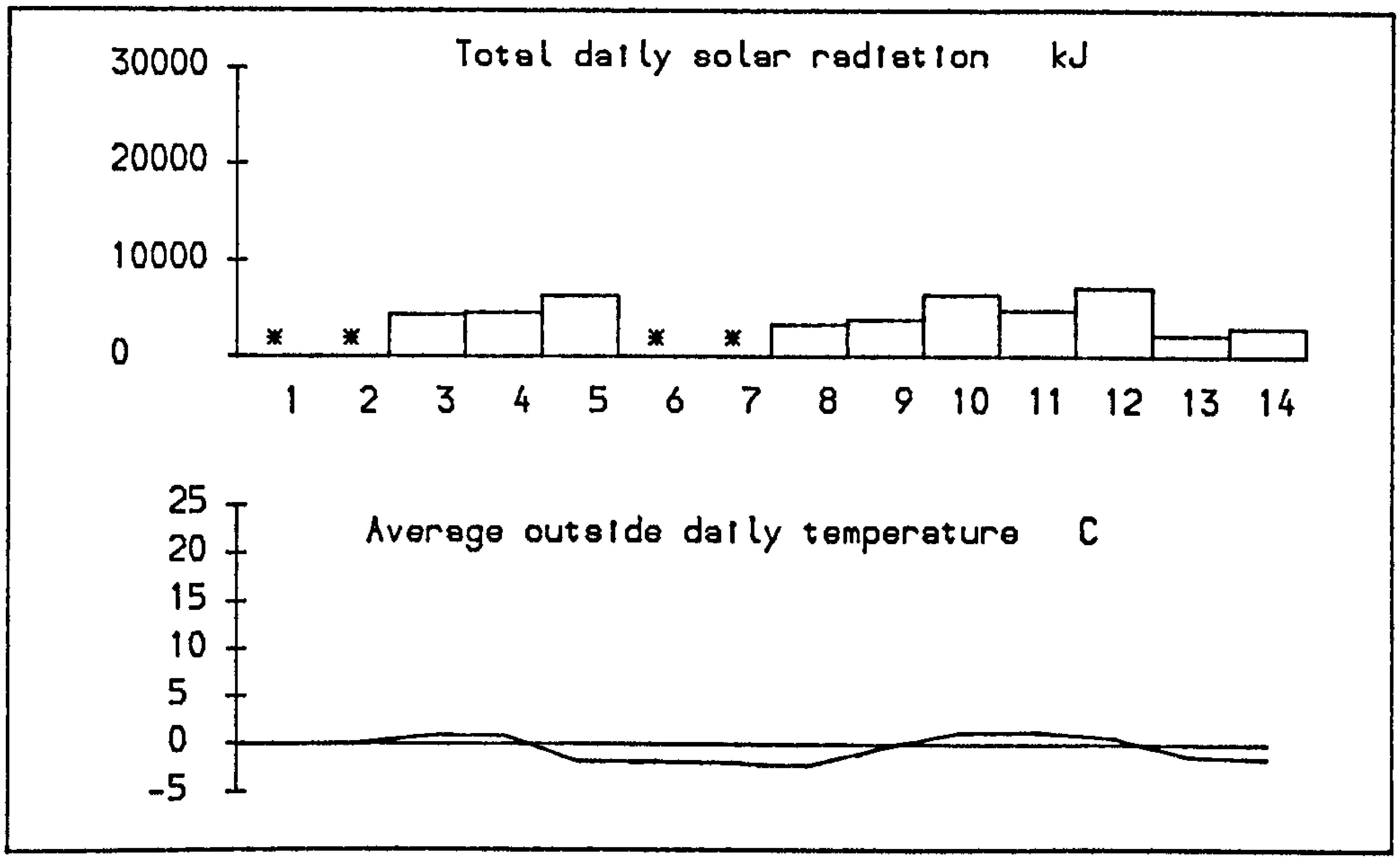
Comparison of actual conservatory output with predicted output

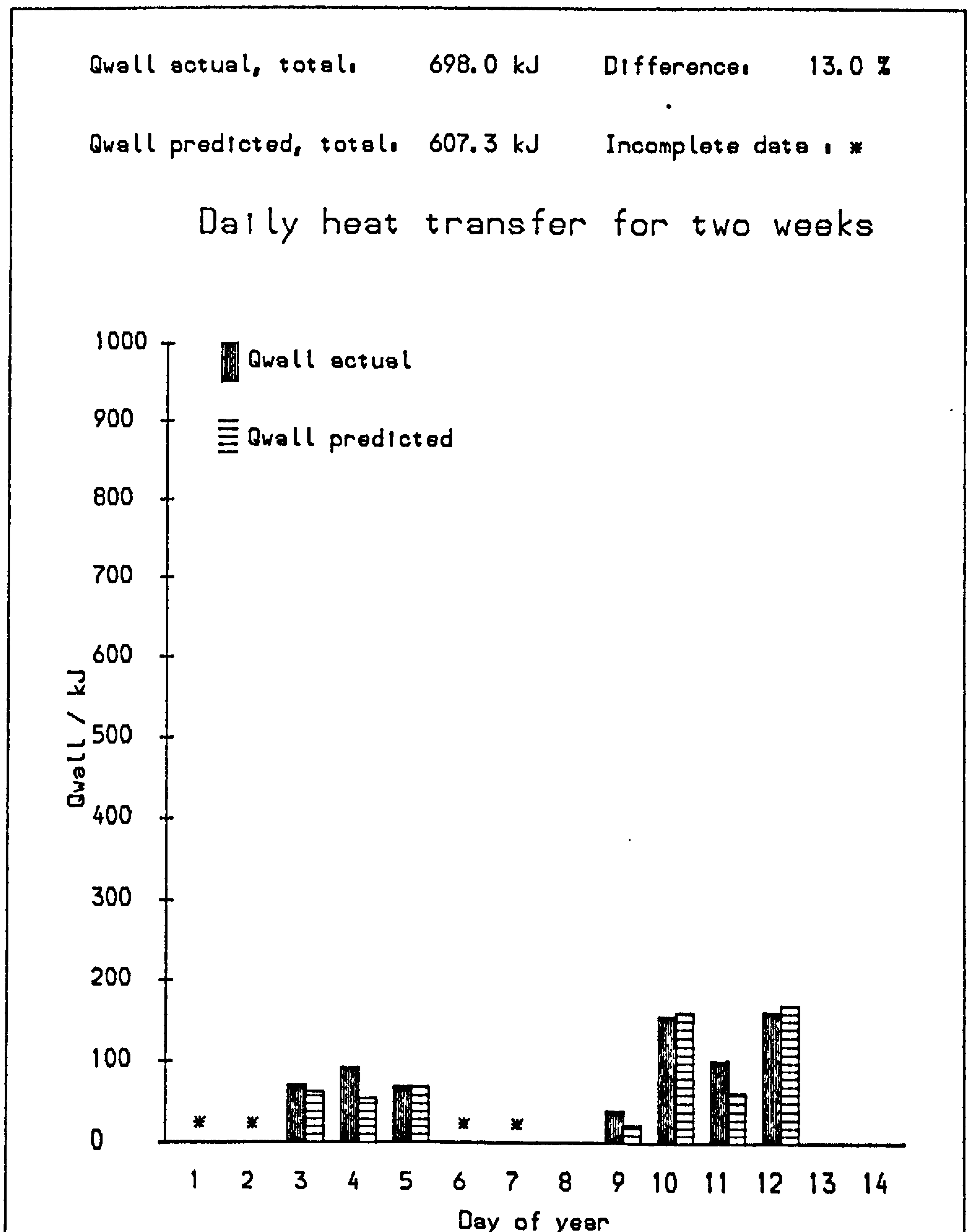
Figure (6.10)



Comparison of actual conservatory output with predicted output

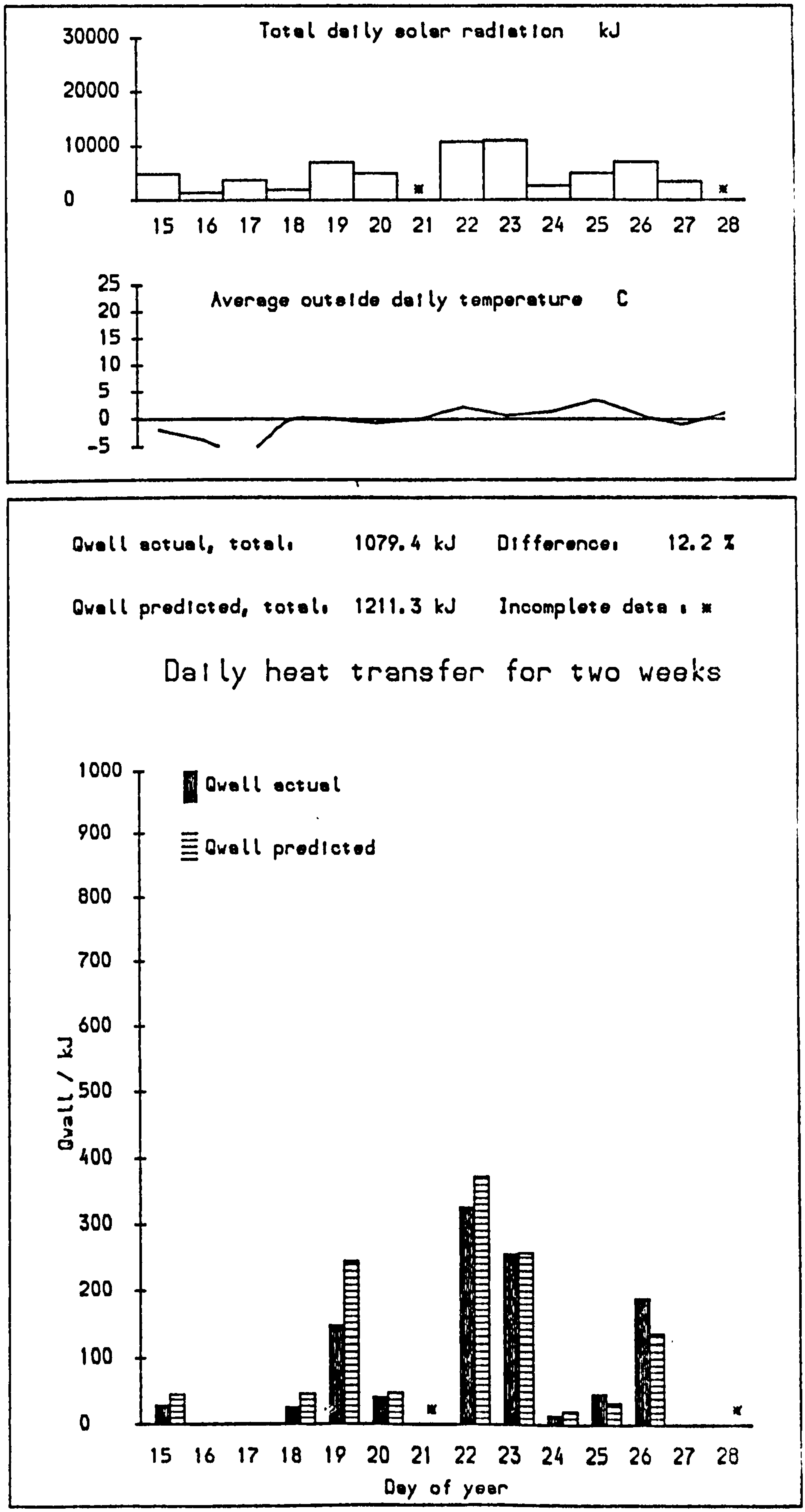
Figure (6.11)





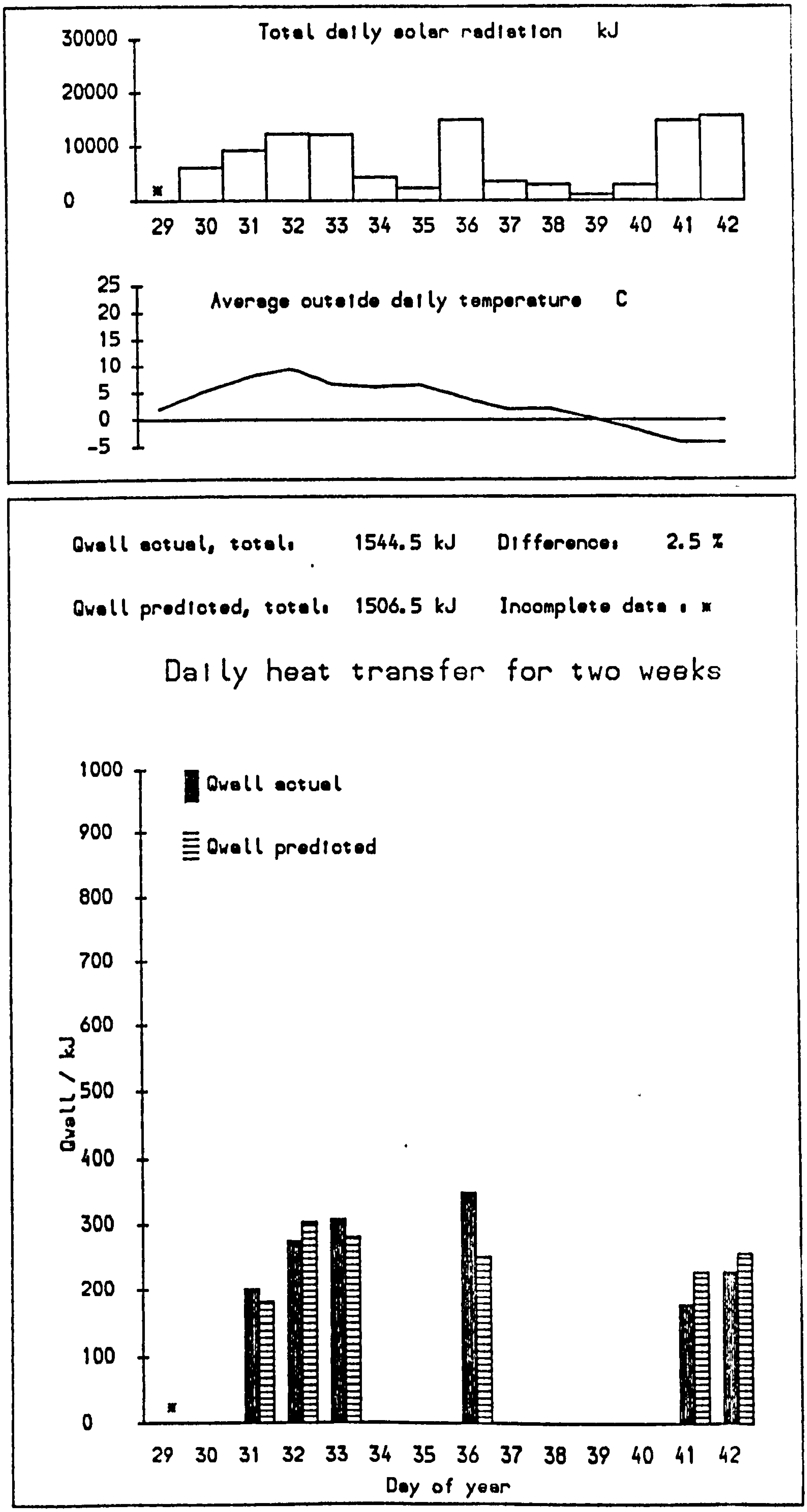
Comparison of actual conservatory output with predicted output

Figure (6.12)



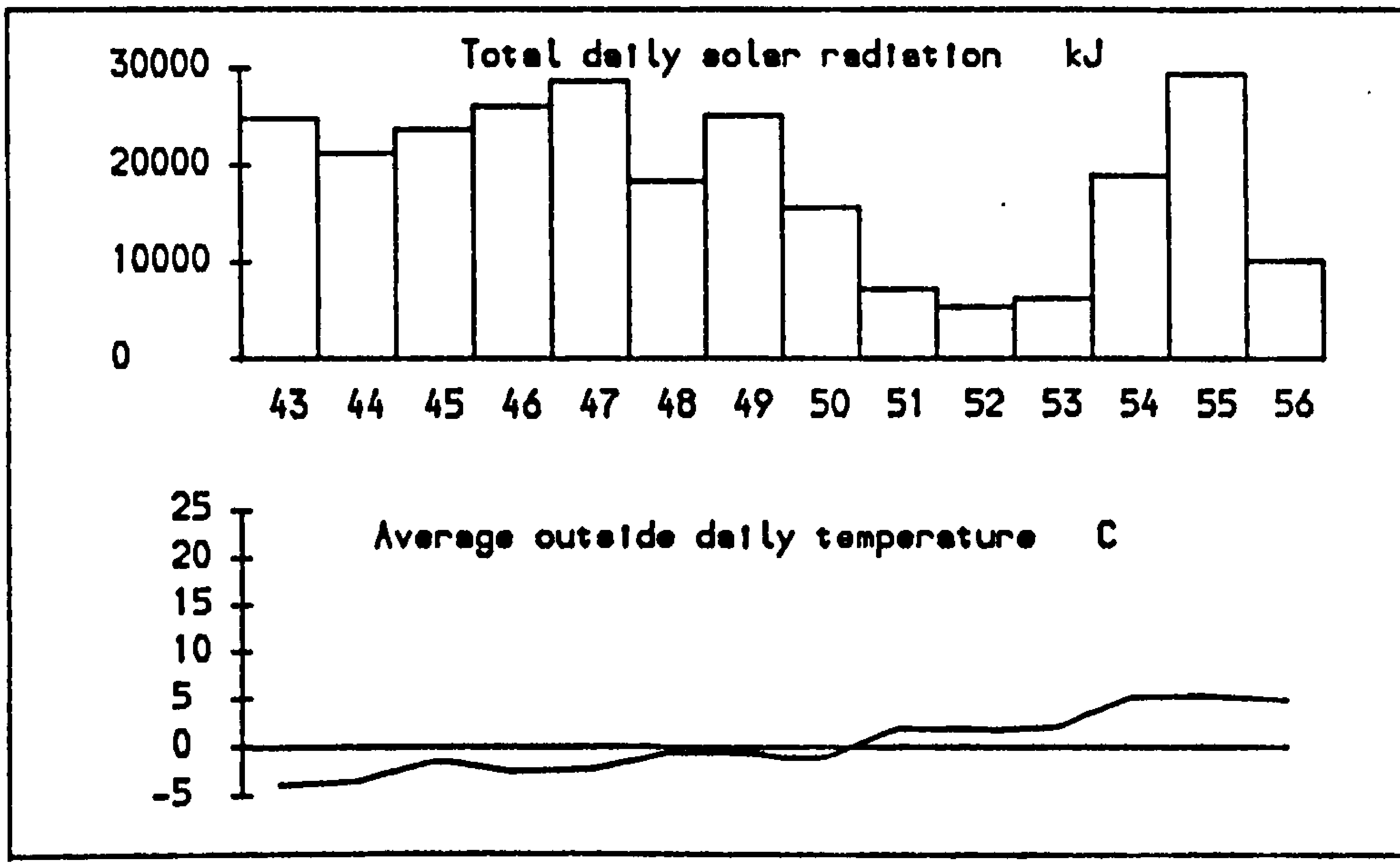
Comparison of actual conservatory output with predicted output

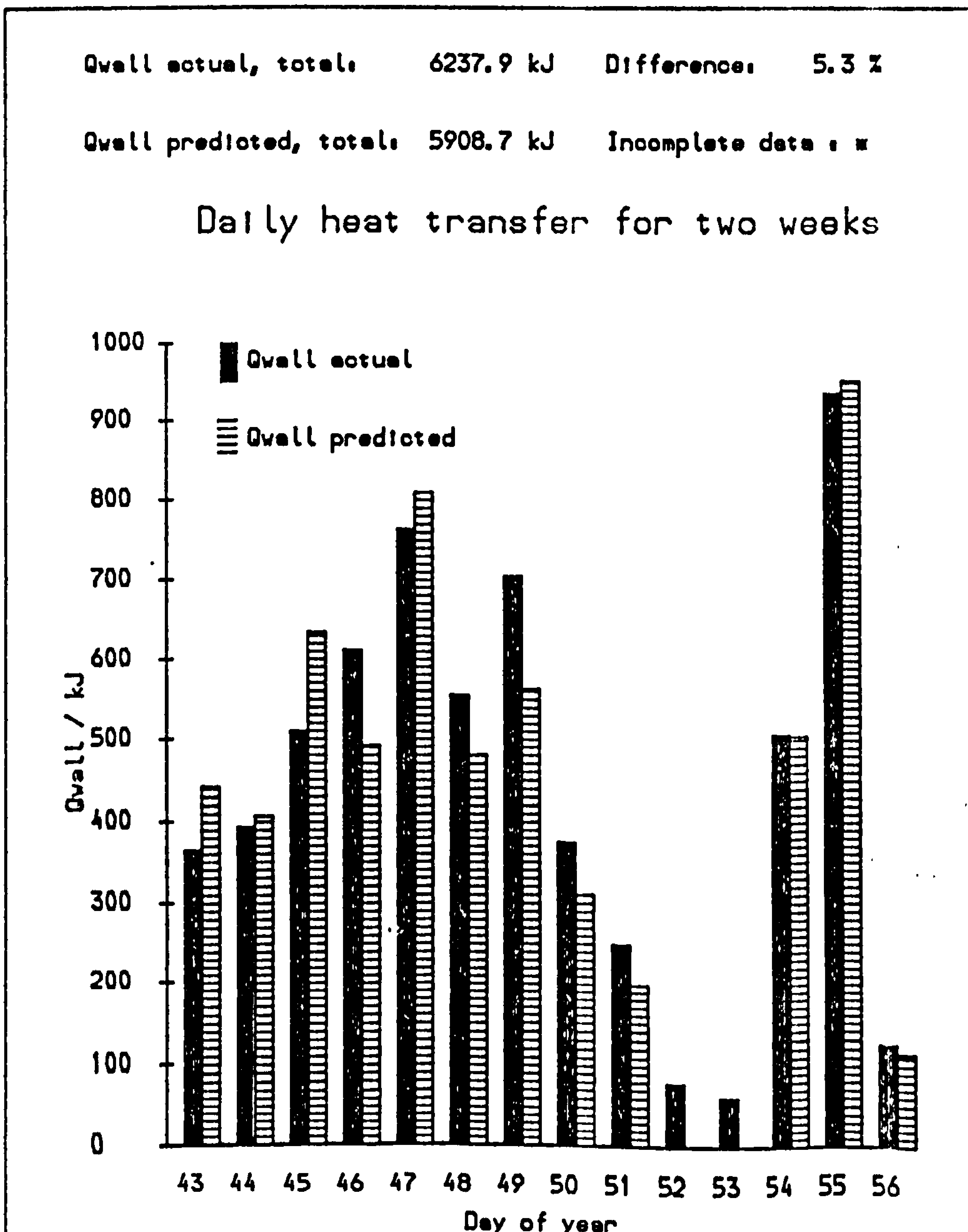
Figure (6.13)



Comparison of actual conservatory output with predicted output

Figure (6.14)





Comparison of actual conservatory output with predicted output

Figure (6.15)

CHAPTER 7 SIMULATION OF CONSERVATORY BEHAVIOUR

7.1 Introduction

From the results of the previous chapter, the behaviour of the model SUNSPACE was considered reliable enough to predict the performance of the conservatory.

Variations were made to the model to control specific variables.

7.2 Criteria for running the model

The model has been used to provide the likely internal gains in the form of prewarmed air supplied either to the slab or the warm air heating unit and the contribution to the reduction of heat loss from the house by having a large expanse of warmer air acting as a buffer zone.

The delivery of prewarmed air to the slab and the house is considered to be the "air gain" and the improvement due to the buffer zone as the "buffer gain".

The fan is assumed to be switched off completely between midnight and 6.00 h. Between 6.00 h and 18.00 h the fan is switched off if the conservatory air temperature is less than $4^{o}C$ to ensure that no freezing could occur in the store. No buffer gain is considered if the outside air temperature is above 20.0 ^{o}C.

7.3 Size of the Conservatory

For the purpose of simulation, the conservatory was assumed to have a floor area of 3.0m width by 1.5m depth and a wall area of 3.0m width by 2.8m height. The conservatory roof sloped down to a height of 2.0m at the front. The wall was assumed to be 30 % glass.

7.4 Monthly and Yearly Output

The model was run for a whole year and the gain by prewarmed air and the contribution of the buffer zone were calculated.

The buffer gain was considered to be the overall gain to the house by having a higher temperature outside the outside wall in comparison to the sol-air temperature at the outside wall had the conservatory not been present. The conservatory will reduce the direct gain to windows by presenting an extra layer of glass in the sun's rays path. This reduction was not taken into account since is was thought that it would be small.

The air gain is assumed to be the increase in temperature of air drawn into the house from the conservatory by comparison to drawing it in from the outside. The air flow was taken to be 0.05 m^3/s. No account was taken of the change in infiltration heat loss of the house. It was assumed that the fan was the primary source of input of fresh air to the house and as such the temperature of the air that it brought in was the most significant factor in heat calculations.

Table 7.1 shows the results for the months of September to May and those for the total heating season for each component:

- Air gain
- Buffer gain
- Total gain
- Total solar radiation on the vertical surface (wall)
- Total solar radiation on the horizontal surface (floor)
- Total solar radiation

The standard deviation is shown, also the figures for 1963 which is considered be the most typical year (C.I.B.S.E.,1970) of the period 1959 - 1968.

The buffer gain varies little from month to month. For an east facing conservatory the buffer gain is between 23 MJ/month in November to 35 MJ/month in May. The results are similar for a west facing surface. For a conservatory facing south the range is from 26 MJ/month in November to 41 MJ/month in February. The standard deviation is low, generally 2 - 5 MJ/month suggesting little variation from year to year.

The gain from pre-warmed air varies considerably from month to month with the total solar input. The most productive months are at the beginning and end of the heating season: the gain to prewarmed air for a south facing conservatory in September is 418 MJ/month and 586 MJ/month in May. Less is found for east and west facing conservatories, 271 MJ/month and 320 MJ/month for September and 428 MJ/month for May for east and west facing conservatories respectively.

The results are however lower than originally suggested in Chapter 1. The final findings are between one half and one third of those expected. The initial calculations were based on 24 hour usage rather than 18 hour usage set out here and that air below 4°C was considered to be useful. Major differences may have occured since the initial calculations were based on average outside air temperatures. This aspect was shown to be particularly important in the thermal behaviour of the conservatory.

The performance of the collector may be expressed as its efficiency in converting the total solar input into useful gains to the house, i.e. the total output as a percentage of the total input. The highest levels of 18% to 20% are achieved in the months of November to January. The poorer performance levels of around 13% occur at the beginning and end of the heating season (September, April and May). The overall efficiency of the heating season for a south facing conservatory is about 14% and 15%-16% for east and west facing conservatories.

It is difficult to quantify the performance of the conservatory per square metre since the total area covered may be considered as either that of the wall or that of the wall and the floor. Table 7.2 shows the results per square metre of wall surface covered and per square metre of wall and floor covered. Considering the conservatory as a large glazed air collector the yearly output for a south facing conservatory is equivalent to 338 MJ/m^2 of wall covered for the prewarmed air gain and 35 MJ/m^2 for the buffer component. This total of 373 MJ/m^2 compares with the value of 544 MJ/m^2 found by MacGregor (1981) in his steady state analysis of glazed masonry wall. Boyle (1985) measured an output of around of 270 MJ/m^2 for the heating season of 81/82 and a theoretical value of 403 MJ/m^2. Although the circumstances are not exactly similar, similar orders of magnitude would be expected.

The buffer component is only relevant to the wall area covered. Considering the total surface area, the prewarmed component is 220 MJ/m^2.

These results are only typical of the conservatory described in 7.3. As shown, the orientation will affect the performance but the size, shape and amount of floor and wall area covered will also affect the performance. These will be discussed below.

7.5 Orientation of the Conservatory

7.5.1 The Effect of Orientation

As discussed in Chapter 3, orientation affects the total solar radiation falling on a given surface and the time of maximum irradiance. Because of the high incidence of non directional diffuse solar radiation, the effect of orientation is less critical than at first appears and offers the designer greater control over the time of solar gain.

The model was run for all orientations between 0° and 360° at 10° intervals for months of the heating season. Cumulative output and solar input for each of these months are shown in Figs (7.1) to (7.9) for the various orientations and different three hour time intervals.

From 6.00 h to 9.00 h there is little or no variation in output with orientation for all months other than May when there is an improvement for conservatories facing between 60° and 180° from North. The output varies from month to month from about 8 MJ in January to 40 MJ in May. The May figure is the peak at 120 MJ and a more typical 30 MJ is to be found for other orientations.

From 9.00 h to 12.00 h all months show an improvement for specific orientations, 170 MJ for the middle of the heating season and 130 MJ for the beginning and end of the heating season due to the sun rising more northerly. For orientations where no direct sunlight would be expected, the output for each month is not appreciably higher than for the earlier interval.

The period of 12.00 h to 15.00 h shows the highest output for each month. The maximum occurs with similar orientations for all months: 180 - 190 MJ.

From 15.00 h to 18.00 h the maximum output occurs at orientations to the west of south. There is an improvement for all months in the output for orientations not facing the sun. This improvement continues from 18.00 h to 21.00 h particularly in the mid season months of January and February. Despite no sun being available during these months at this time, there is a considerably higher contribution than during the early morning due to the conservatory's inherent storage. A peak occurs for the winter months at a similar orientation (200° - 230°) to the peak at the previous interval thanks to the greater level of heat stored from earlier in conservatories of this orientation. The months that receive sunshine at this time have a more noticeable peak at a more westerly orientation but the output at other orientations is similar to that of the winter.

All months have a significant output in the last time interval, in winter it is commensurate with the early afternoon. The orientation of the conservatory has some effect on the months at the beginning and end of the heating season at orientations that are more likely to have produced the highest storage.

The orientation of the conservatory is not only useful for gauging the time of maximum gain but also upon the conservatory's amount of natural storage. Whilst southerly aspects give the maximum overall gains, a west of south conservatory provides good output in the afternoon and early evening and also charges the conservatory's natural storage for the late evening.

If a perfect store could be developed and attached to the conservatory, a south facing conservatory would be the most economical and productive. Since this is unlikely, there will be a trade off between the store used and the orientation of the conservatory.

7.5.2 Buffer Gain with Varying Orientation

The contribution made by the conservatory acting as a buffer zone for various orientations is shown in Table 7.3. October and April are taken to represent the beginning and end of the heating season and January to represent the middle.

The most striking feature is the lack of variation for the different orientations. At the beginning and end of the heating season there is less than 30 % total variation with orientation and for January it is under 4 %.

For orientations that are more likely to receive direct sunlight such as 180 there would have been a larger direct gain even without the addition of a conservatory, hence the net gain by the conservatory is not large.

The mid-season month has a considerably higher gain than the others due to the lower solar radiation and the shorter periods of sunshine reducing the normal direct gain.

Since the orientation has little effect upon the buffer component, the conservatory's use as a buffer zone is not restricted by location. Its use on a north facing surface is feasible and as size and shape are unlikely to affect its performance, the use of porches on northern surfaces is practicable particularly with the reduction of draughts through the door.

7.6 Variation of the Size of the Conservatory

One would expect the size of the conservatory to determine the likely output and to some extent this is so. The model was used to simulate the monthly performance of a conservatory of different sizes but with the shape remaining the same, hence the ratio between all the critical dimensions remained constant.

Taking the original size described in 7.3 as 100%, as the total surface area, the sum of the floor area and the wall area, was varied between 4% and 400% of this figure. Although these two extremes are unlikely sizes for a conservatory, they give an indication of the broad trend. Fig (7.10) shows the results of this for the months of October, January and April for conservatories facing each of the compass points.

Kew weather data from 1963 were used for the simulation.

The monthly output increases with the size for all months and for all orientations at a fairly steady rate after 50 % of the original size. However the increase is not proportional to the increase in size.

For the months at the beginning and end of the heating season, a doubling in total surace area results in a reduction in the output per square metre of about a quarter and quadrupling the area a reduction of about one half. The mid season is less affected with reductions of a fifth per square metre and a third per square metre for doubling and quadrupling respectively.

The perceived reduction in output per square metre of total surface area is almost certainly due to the increase in surface area that is not at the time benefiting from direct solar radiation such as the floor receiving little radiation in mid winter months.

The relationship between the contribution from the surfaces from month to month will be discussed below.

7.7 The Shape of the Conservatory

Generally the shape of the conservatory is determined by manufacturers' styles and sizes available or by planning constraints. If the conservatory is to be used in some way as a passive solar collector, its shape is unlikely to be considered as a major criterium, location, construction and size are likely to be the foremost considerations.

The prime criteria for the conservatory's output are the area of wall and floor covered. Both the wall and floor act as radiators of the conservatory's solar input and as natural stores for the heat gained. The wall acts as a means of direct heat conduction given a positive heat gradient between the conservatory and the inside of the house and as a buffer zone given a negative gradient. The conservatory is above all a means of enclosing these two surfaces for the purpose of heat gain. Should the conservatory also contain a third surface such as a partition wall, this would also contibute to its performance.

Should the size of the wall and floor of the conservatory remain constant and the shape of the conservatory be varied there is little change in performance.

Considering the front height dimension to be:

$$Hfront = k \times Hwall \qquad (7.1)$$

where k varies between zero and unity i.e the conservatory changes from a triangular section to a rectangular section, there is no measurable change in performance.

The nett contribution from either surface is determined by the amount of solar radiation that it receives which in turn is dependent upon the weather and the position of the sun. At different times of the year, the contribution from each surface will vary. In the summer, with a high sun, the floor will be the major contributor and in the winter, with a low sun, it will be the wall.

7.7.1 Variation of the Size of the Floor

By keeping constant the area of the wall covered, the effect of changing the floor area may be ascertained. The height was kept at 2.8m at the wall, the roof sloping down to 2.0m at the front. The width was 3.0m and the depth was varied between 0.05m and 4.0m. Obviously at the low levels, the conservatory cannot be considered as a conservatory but rather as a narrow air collector. The results are shown in Fig (7.11).

As would be expected, there is an increase in total gain with increasing floor area for all orientations but it is particularly striking for the months at the beginning and end of the heating season. For January, there is only very small variation in output with floor area, the graph being almost flat. The relationship is not linear since increasing the floor area reduces the effect of the additional contribution of the floor. In January, an increase in depth from 1.0m to 2.0m, equivalent to a doubling of the floor area from $3m^2$ to $6m^2$, improves the output by 25 MJ/month for south facing conservatories and 12 - 13 MJ/month for other orientations. An increase from 2.0m to 3.0m only improves the output by 6 - 7 MJ/month for all orientations and even a doubling from 2.0m to 4.0m only improves the output by 8 - 10 MJ/month.

Months at the beginning and end of the heating season suffer less from a reduced contribution with increased size. In April in particular, there is much to be gained by increasing the floor area with an increase in depth from 1.0m to 2.0m resulting in an improvement of 100 - 120 MJ/month depending upon the orientation and an increase from 2.0m to 4.0m giving an improvement of 110 - 125 MJ/month.

Months such as September, April and May will benefit greatly from a larger floor area since the sun is relatively high giving a large horizontal solar radiation component. However these are also the months when the conservatory's contribution may be least required and hence the additional expense of a conservatory covering a larger floor area may not be warranted.

7.7.2 Variation of Wall Size

A similar procedure was adopted for the variation in wall size. The floor area was left as in 7.3 with the height of the wall varied from between 0.5m and 4.0m corresponding to an area of between $1.5m^2$ and

$12m^2$. The results are shown in Fig (7.12).

The most striking feature is the smallness of the improvement with increasing size. This is due in part to the effect of diffuse radiation which is more significant on the horizontal than on the vertical, hence an increase in wall area will not benefit greatly from this radiation.

January shows the most consistent improvement. Initially the increase is about 10 MJ/m^2 month for a south facing wall and 6 - 7 MJ/m^2 month for the other surfaces. Above a height of 1.5m this settles to about 7 MJ/m month for the south and 5 MJ/m^2 month for the others. This rate continues with increasing height.

The improvements achieved initially during October and April are 11 and 12 MJ/m^2 a month respectively for a south facing conservatory. Above a height 1.5m this is reduced to 6 and 7 MJ/m^2 a month. For other orientations the improvement is lower at about 3 MJ/m^2 a month and 5 MJ/m month for October and April above a height of 1.5m. Improvement decreases with height.

7.7.3 Variation of Annual Output with Surface Size

The overall output for the heating season September to May for different depths and heights are shown in Tables 7.4 and 7.5.

Over the heating season, the increasing size of the floor (Table

7.4) increases output but with a decreasing improvement per square metre of floor space added. This suggests that there is a maximum size above which there is little to be gained. Since this occurs with conservatories over 4.0m depth, an unlikely dimension, it was not thought to be worth investigating.

If the heating season is considered to be from October to April, a similar trend is found, although the increases are lower.

A similar, although less marked, relationship is found with the floor, although the improvement per sqare metre is lower. Considering a shorter heating season does little to affect the rate of improvement.

7.7.4 Variation of the Proportion of the Floor and Wall

A total surface area of $13m^2$ was selected and of this the proportion of floor was varied between 20% and 80%. The wall was considered to be 30% glass and the front height was taken as 70% of the rear height. The results are shown in Fig(7.13) for the proportion of the surface area that is floor against the monthly output.

For months at the beginning and end of the heating season, the maximum output occurs with 60% floor area and 40% wall area. For the mid season months there is a fairly steady output of up to about 60% floor when there is a slow decline.

Considering a whole heating season, September to May, the maximum output occurs with 60% floor level. For a shorter heating period, a ratio of 50% to 60% is more beneficial for south and east facing conservatories with 60% floor for other orientations.

7.8 Summary and Conclusions

7.8.1 The buffer component gain varies very little from month to month whilst the gain to prewarmed air varies with the proportion of solar radiation received. The prewarmed air gain also varies from year to year with weather, unlike the buffer gain which varies little.

7.8.2 The overall efficiency is 14% to 16% for the heating season with 20% being achieved between November and January.

7.8.3 Orientation particularly affects the time of maximum output. Generally the orientation which benefits the most at any time interval is that which faces the sun. In the late afternoon and early evening during the winter, the maximum output occurs for orientations that received greater solar radiation earlier.

7.8.4 Western orientations fare very well for afternoon and early evening gain but easterly orientations have little contribution even in the morning since the conservatory starts from cold with little or no residual storage. Easterly orientations are not worth considering for the prewarming of air.

7.8.5 The buffer gain is not affected much by orientation. It is highest in the winter.

7.8.6 There is a large increase in output with size up to a total surface area of $6m^2$, beyond this there is a lower increase at a declining rate of growth with area.

7.8.7 The shape of the conservatory affects the total output. Ideally the floor should be between 50% and 60% of the total surface area.

7.8.8 The size of the floor is more important than that of the wall. Increasing floor area is more likely to improve output than increasing wall area. The shape of the conservatory covering the wall and floor area does little to affect the output.

	EAST			SOUTH			WEST		
	Av.	S.D.	1963	Av.	S.D.	1963	Av.	S.D.	1963
SEPTEMBER									
Air gain	271	14	263	418	44	381	320	25	298
Buffer	27	1	26	35	3	32	32	3	29
total	298		289	453		413	353		327
Qvert	1057	75	998	2023	297	1779	1439	182	1293
Qhoriz	900	47	859	1190	111	1085	960	69	889
total	1957		1857	3213		2864	3299		2182
OCTOBER									
Air gain	196	7	193	309	34	280	228	16	217
Buffer	24	2	23	30	3	27	27	3	25
total	220		216	339		307	255		242
Qvert	649	29	621	1472	250	1259	902	117	822
Qhoriz	541	25	518	689	59	629	574	40	536
total	1190		1139	2161		1888	1474		1358
NOVEMBER									
Air gain	134	7	137	194	20	193	150	7	153
Buffer	23	2	20	26	2	23	25	2	22
total	157		157	220		216	175		175
Qvert	311	36	317	774	150	758	429	42	447
Qhoriz	268	23	281	319	31	329	281	21	294
total	579		598	1093		1087	710		741

TABLE 7.1 Summary of results from computer model /MJ

	EAST			SOUTH			WEST		
	Av.	S.D.	1963	Av.	S.D.	1963	Av.	S.D.	1963
DECEMBER									
Air gain	106	8	102	153	11	139	119	8	116
Buffer	26	3	29	28	3	29	27	3	29
total	132		131	181		168	146		145
Qvert	192	21	191	566	100	472	285	31	283
Qhoriz	167	19	172	198	22	194	179	20	183
total	359		363	764		666	464		466
JANUARY									
Air gain	111	15	74	160	25	106	123	16	82
Buffer	29	5	43	31	5	44	30	5	43
total	141		117	191		150	153		125
Qvert	254	22	243	65	115	591	346	43	326
Qhoriz	221	17	217	258	28	251	231	20	227
total	475		461	911		842	577		553
FEBRUARY									
Air gain	141	17	99	201	28	176	158	14	130
Buffer	26	4	38	29	4	39	28	5	39
total	167		137	230		215	186		169
Qvert	398	49	389	841	196	908	525	70	595
Qhoriz	345	36	342	411	50	432	360	36	378
total	743		731	1252		1340	885		973

TABLE 7.1 contd. Summary of results from computer model / MJ

	EAST			SOUTH			WEST		
	Av.	S.D.	1963	Av.	S.D.	1963	Av.	S.D.	1963
MARCH									
Air gain	250	28	237	377	60	359	289	31	280
Buffer	31	3	29	37	4	36	35	3	33
total	281		266	414		395	324		313
Qvert	858	153	778	1725	387	1615	1161	193	1081
Qhoriz	729	107	683	946	161	886	772	101	742
total	1587		1461	2671		2501	1933		1823
APRIL									
Air gain	323	19	329	445	46	445	368	36	383
Buffer	31	2	30	38	3	36	35	3	34
total	354		359	483		481	403		417
Qvert	1184	100	1192	1926	260	1906	1526	207	1591
Qhoriz	1057	74	1075	1342	140	1353	1118	109	1167
total	2241		2267	3268		3259	2644		2758
MAY									
Air gain	428	29	421	586	56	519	470	27	433
Buffer	35	3	35	44	3	40	38	2	36
total	463		456	630		559	508		469
Qvert	1693	139	1646	2591	311	2203	2061	169	1814
Qhoriz	1524	107	1478	1966	192	1752	1567	105	1457
total	3217		3124	4557		3954	6828		3271

TABLE 7.1 contd. Summary of results from computer model /MJ

	EAST		SOUTH		WEST	
	Av.	1963	Av.	1963	Av.	1963
HEATING SEASON						
Air gain	1960	1855	2843	2450	2225	2092
Buffer	252	273	298	306	277	290
total	2212	2128	3141	2748	2502	2382
Qvert	6095	6375	12571	11491	8674	8252
Qhoriz	5751	5625	7319	6910	6042	6026
total	11846	12000	19890	18401	14716	14278

TABLE 7.1 contd. Summary of results from computer model / MJ

Qvert : total solar radiation on vertical surface /MJ

Qhoriz: total solar radiation on horizontal surface /MJ

	Buffer Gain /m^2 wall	Air Gain /m^2 wall	Q/m^2 wall	Air Gain/m^2 wall & floor	Q/m^2 wall & floor
OCTOBER					
East	2.8	23	77	15	92
South	3.6	37	175	24	168
West	3.2	27	107	18	114
JANUARY					
East	3.4	13	30	9	37
South	3.7	19	78	12	71
West	3.6	15	41	10	45
APRIL					
East	3.7	38	141	25	174
South	4.5	53	229	34	253
West	4.0	44	181	29	214
HEATING SEASON					
East	30	233	726	152	918
South	35	338	1497	220	1541
West	33	265	1032	172	1142

Q : Solar input / MJ/month

All units : MJ/month

TABLE 7.2 Input and Output per square metre for the wall and the wall & floor.

Orientation:	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	360°
OCTOBER	21.7	21.5	26.1	25.0	26.5	26.9	27.4	26.8	25.2	23.0	21.0	21.7
JANUARY	42.7	42.8	43.3	44.2	43.8	44.1	43.6	46.3	42.9	42.9	42.9	42.9
APRIL	28.7	29.0	30.4	33.9	36.1	36.7	36.8	35.6	33.6	31.0	29.0	28.9

Conservatory size: floor: 3.0m x 1.5m wall: 3.0m x 2.8m

TABLE 7.3 Buffer Gain for various orientations / MJ/month.

X =	1.0	2.0	3.0	4.0
North	1534	2010	2362	2619
improvement/m^2	187	147	108	79
East	1788	2320	2709	2986
improvement/m^2	208	165	119	85
South	2491	3096	3514	3802
improvement/m^2	242	186	127	87
West	2029	2559	2935	3199
improvement/m^2	209	164	115	80

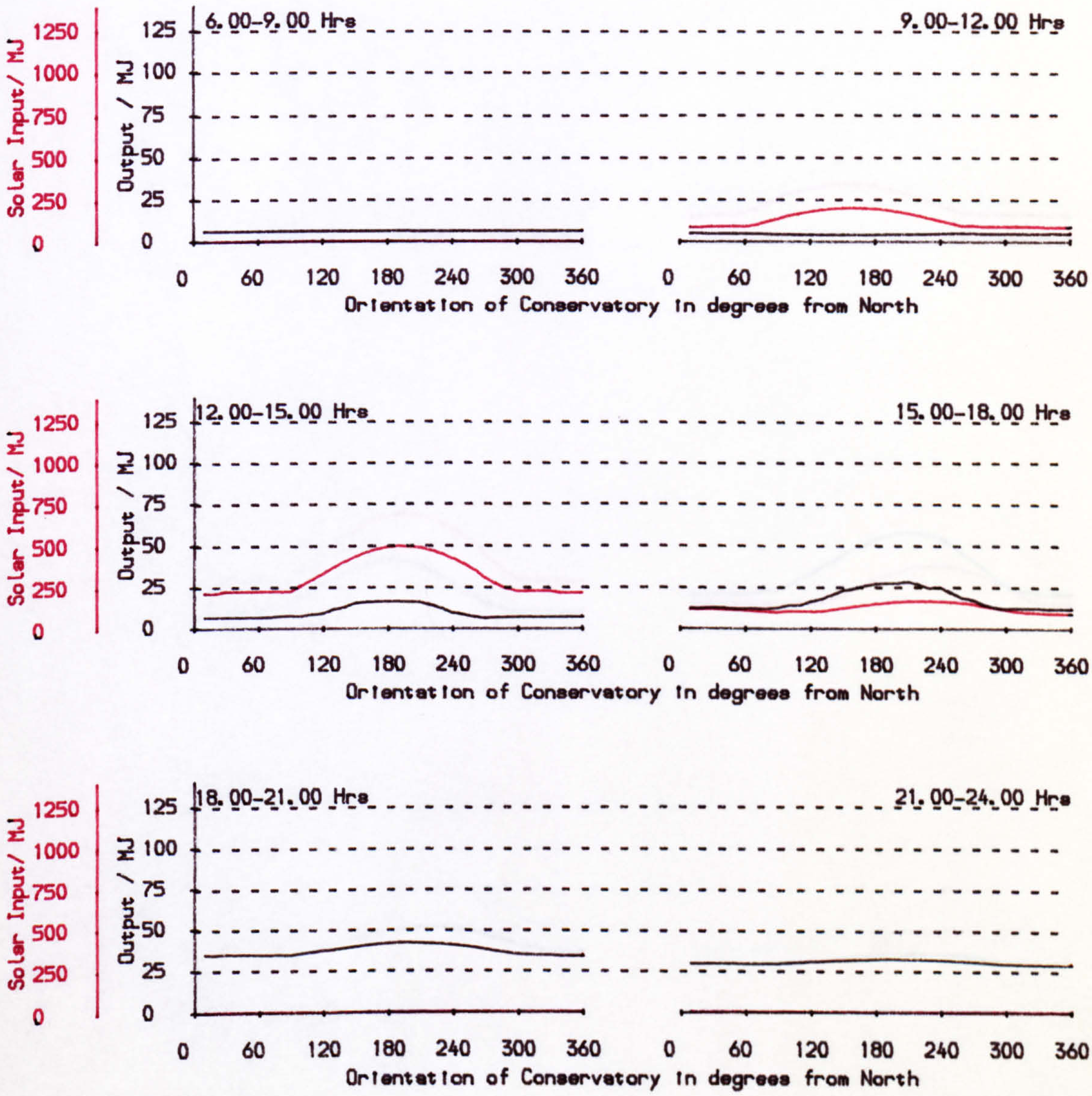
wall= 3.0m x 2.8m   floor= 3.0m x X   Units: MJ

TABLE 7.4 Yearly Output with Varying Floor Depth.

X =	1.0	2.0	3.0	4.0
North	1657	1766	1866	1959
improvement/m^2	29	36	33	31
East	1898	2040	2163	2273
improvement/m^2	45	46	39	36
South	2430	2731	2960	3141
improvement/m^2	113	93	70	59
West	2041	2253	2468	2573
improvement/m^2	74	67	55	47

wall= 3.0m x X   floor 3.0m x 1.5m   Units: MJ

TABLE 7.5 Yearly Output with varying Wall Height



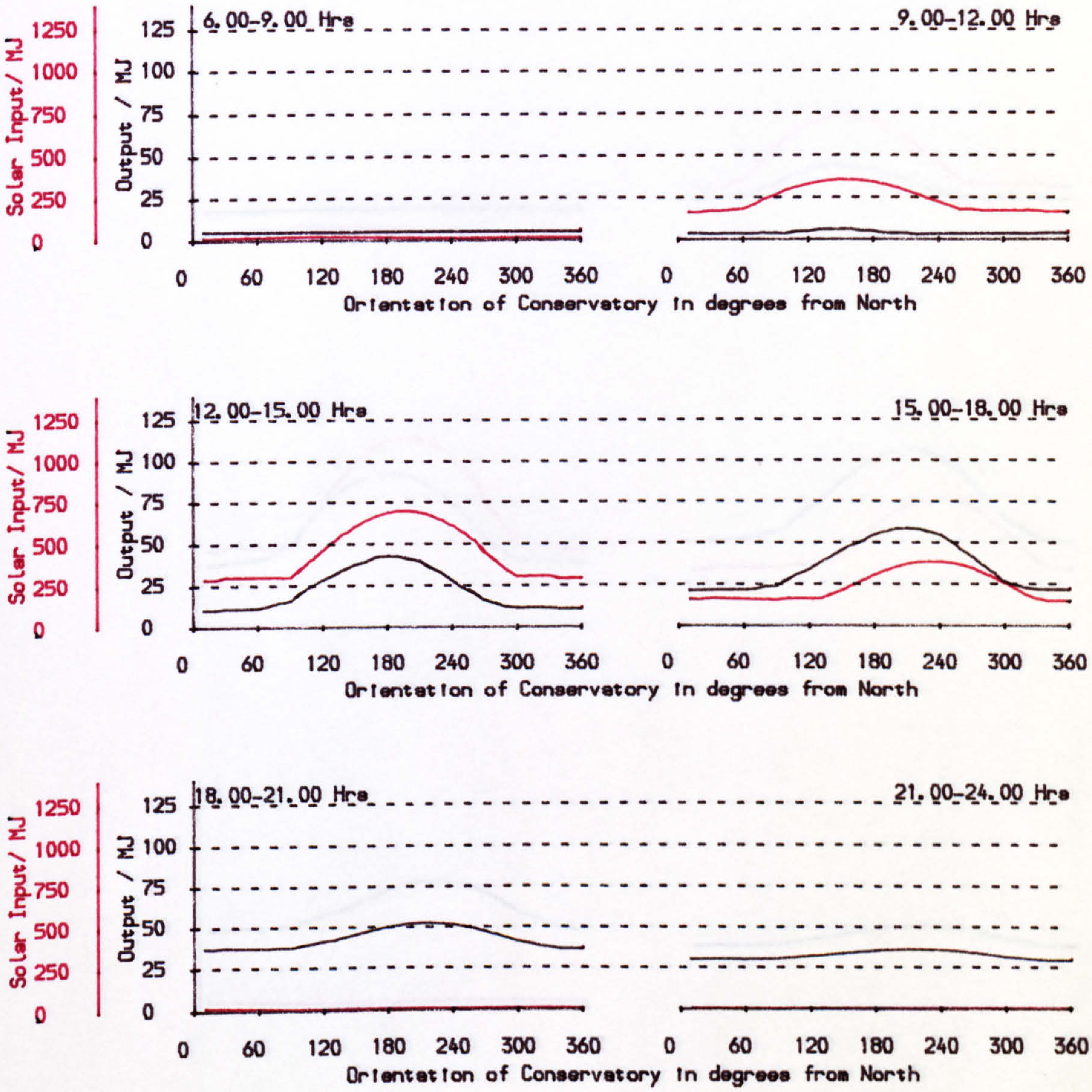
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : January

Fig 7.1

Kew weather data 1963



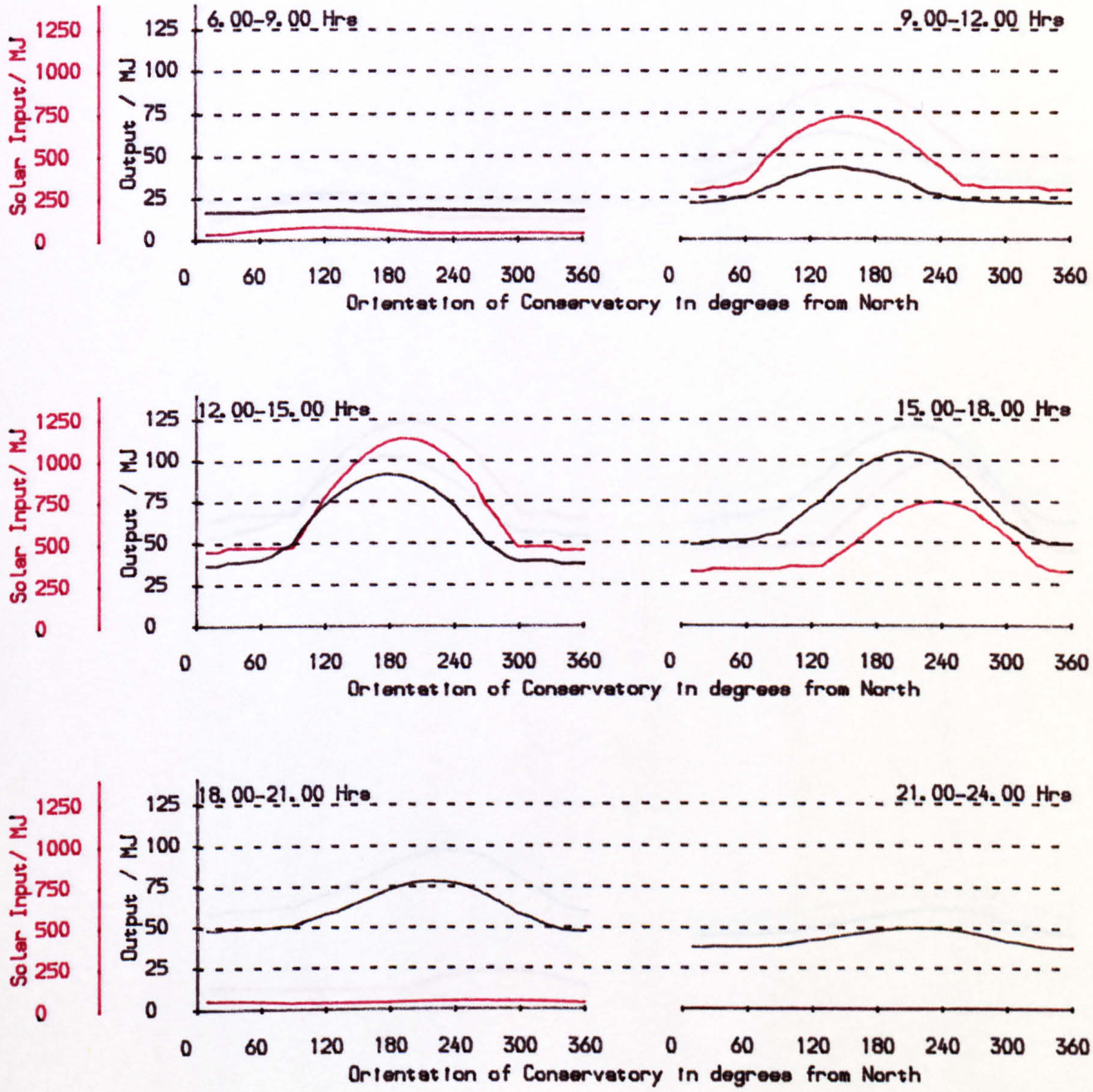
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : Febuary

Fig 7.2

Kew weather data 1963



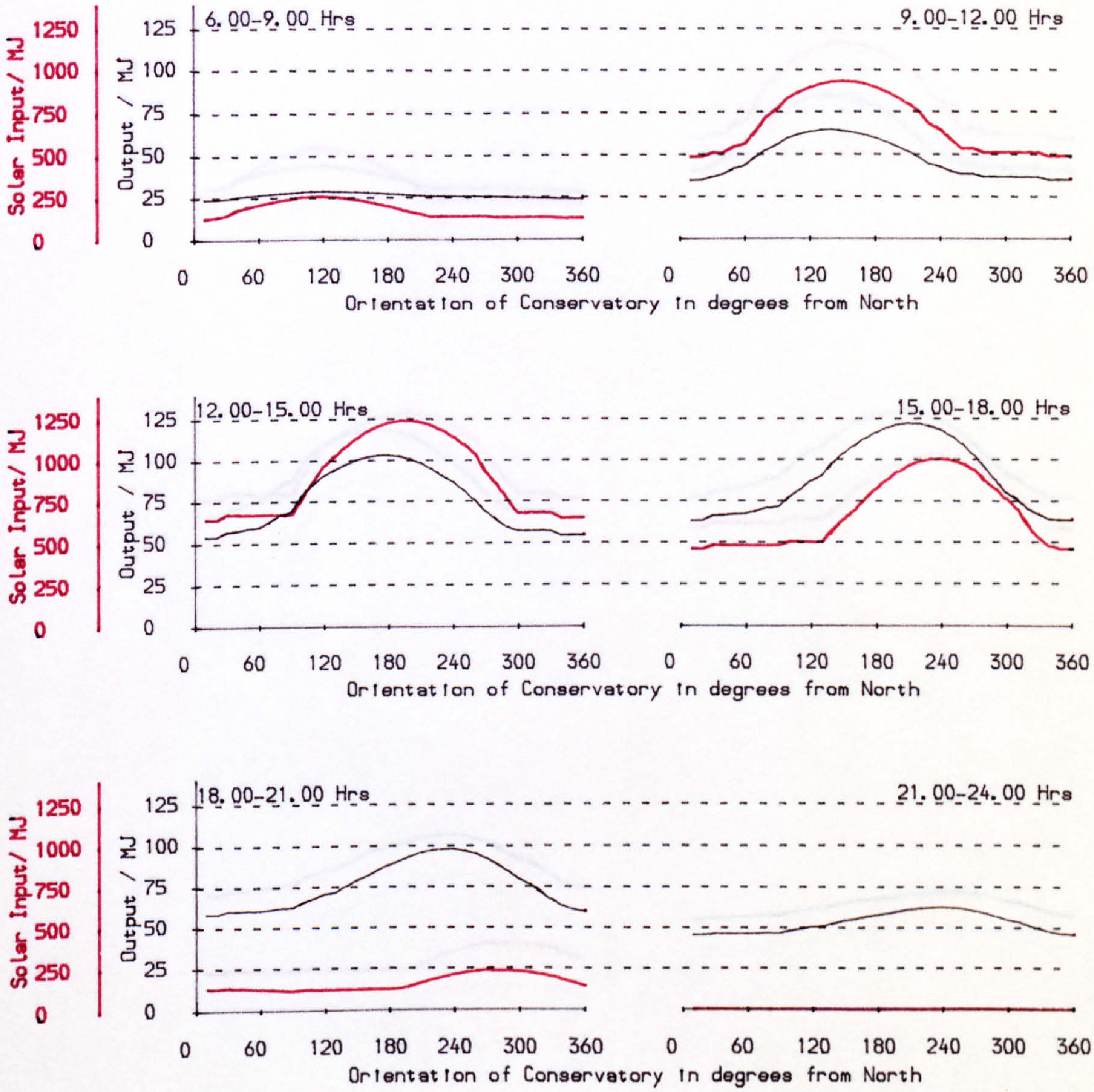
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : March

Fig 7.3

Kew weather data 1963



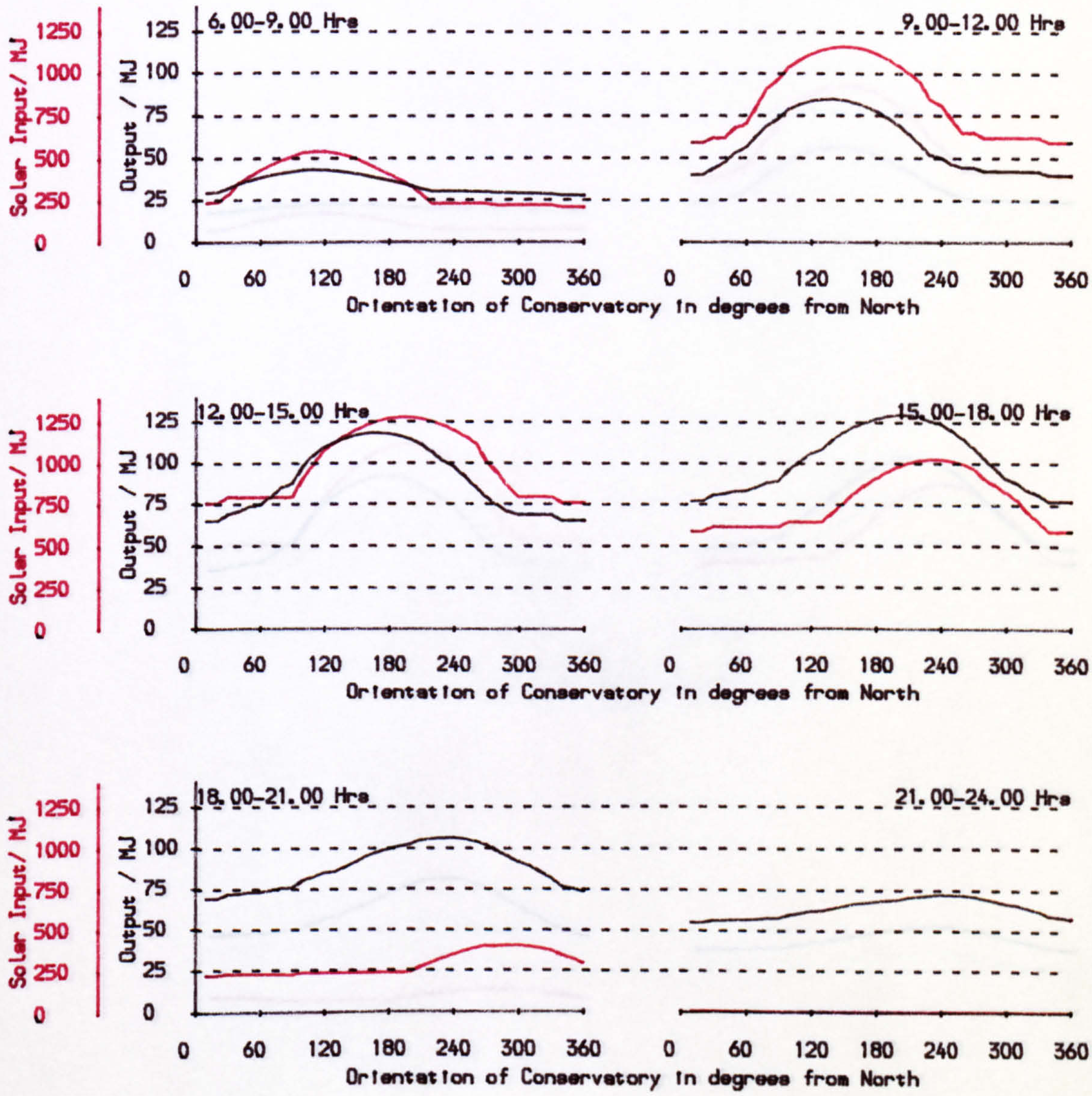
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : April

Fig 7.4

Kew weather data 1963



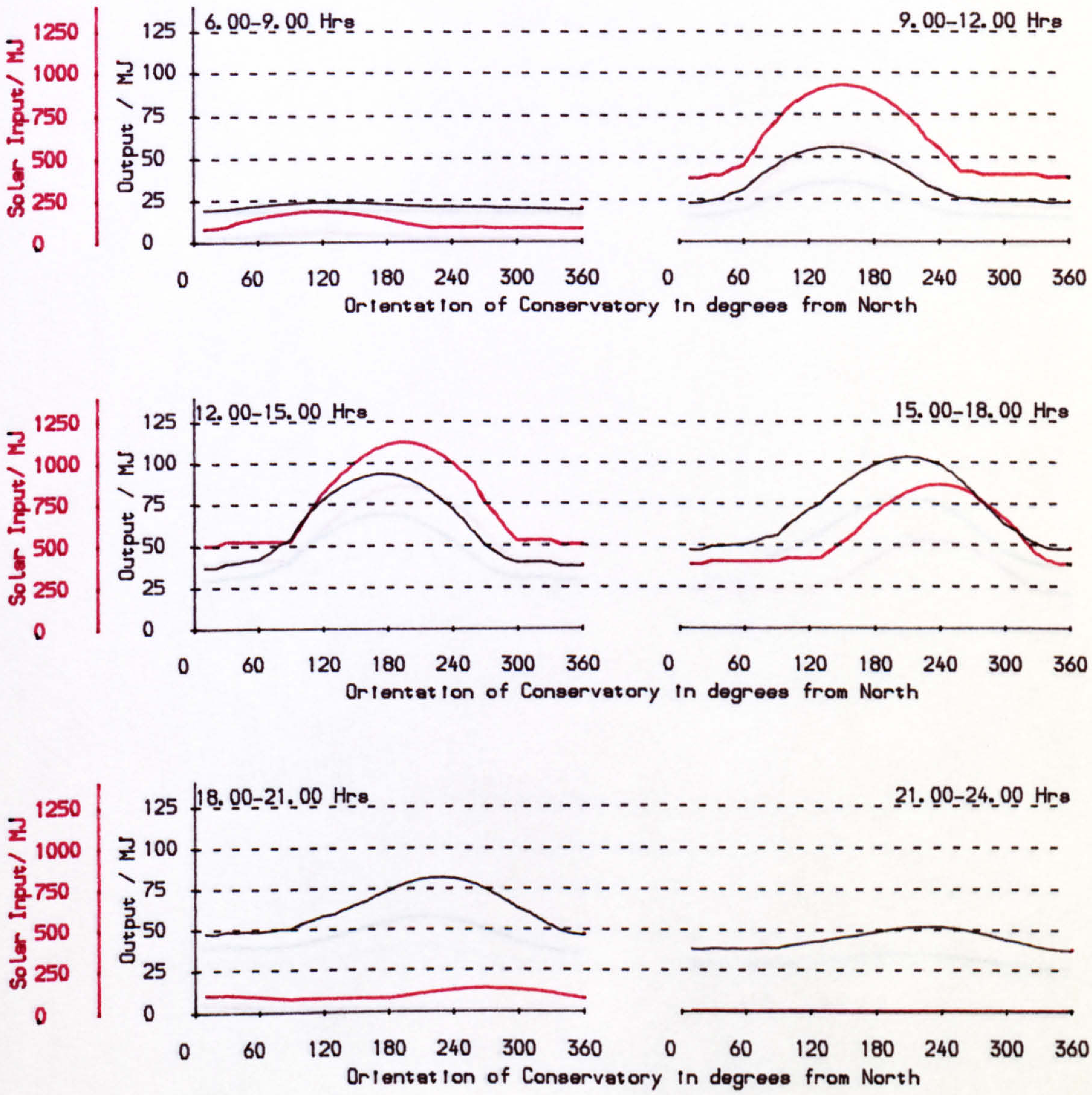
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : May

Fig 7.5

Kew weather data 1963



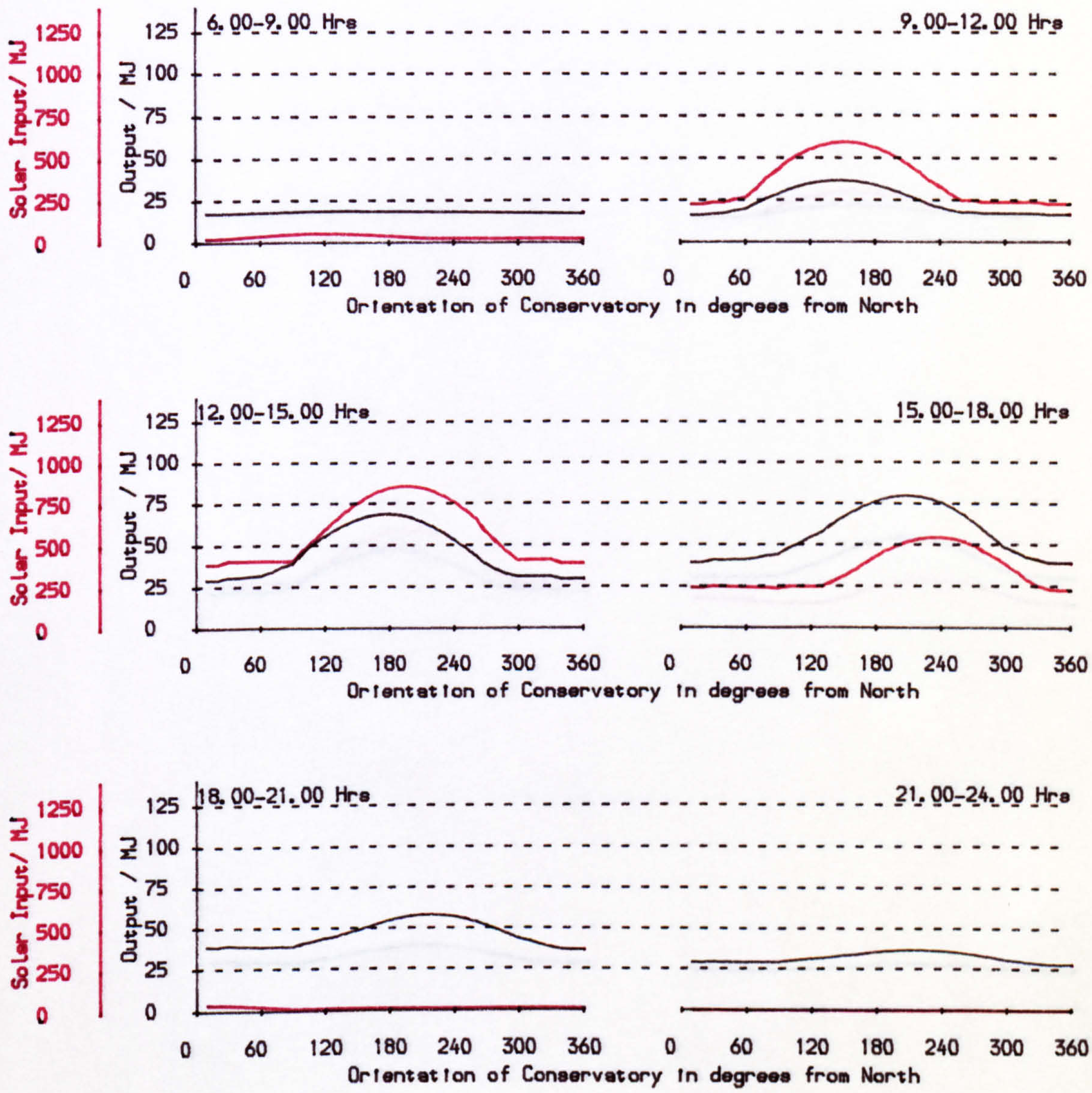
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : September

Fig 7.6

Kew weather data 1963



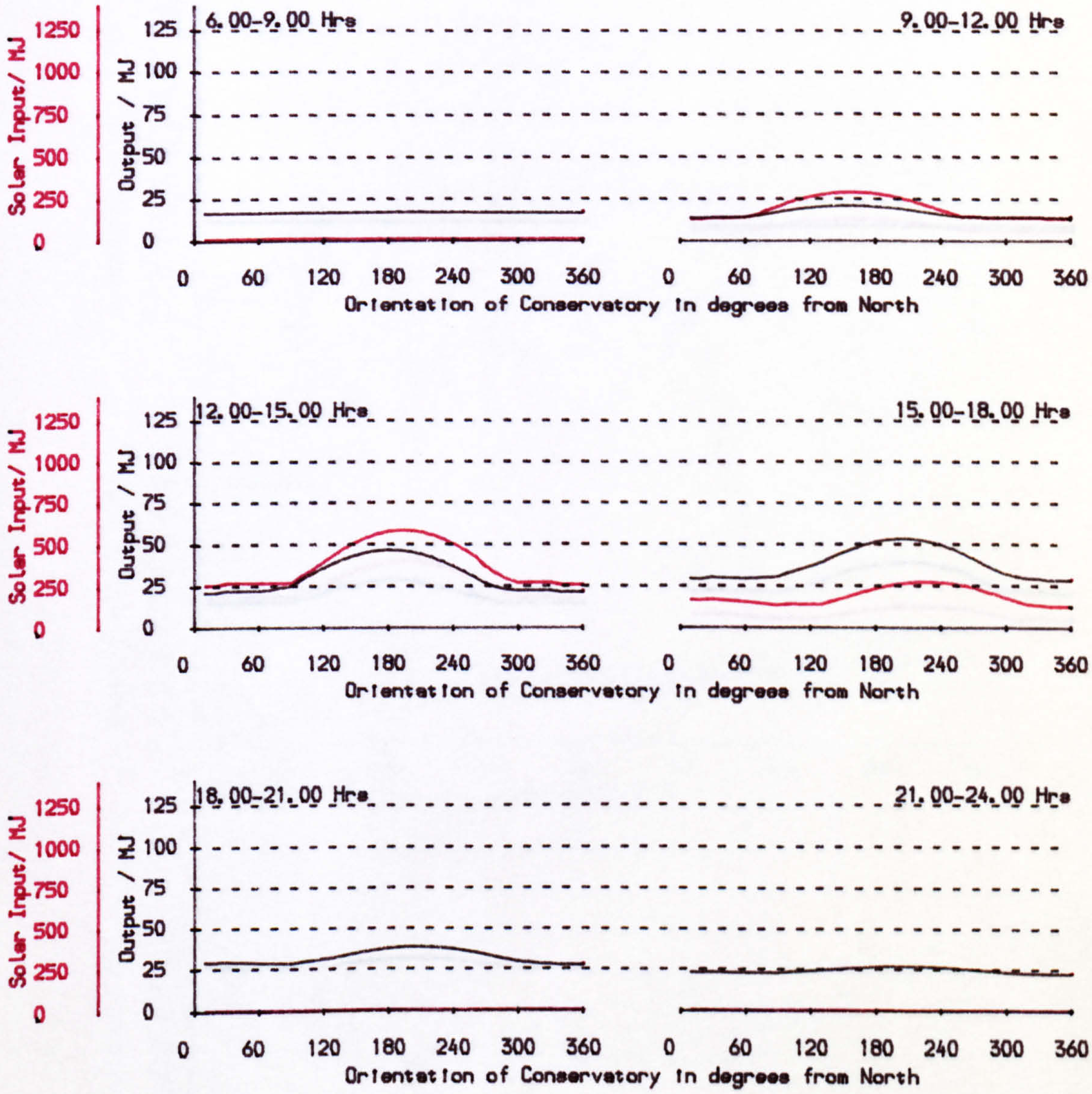
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : October

Fig 7.7

Kew weather data 1963



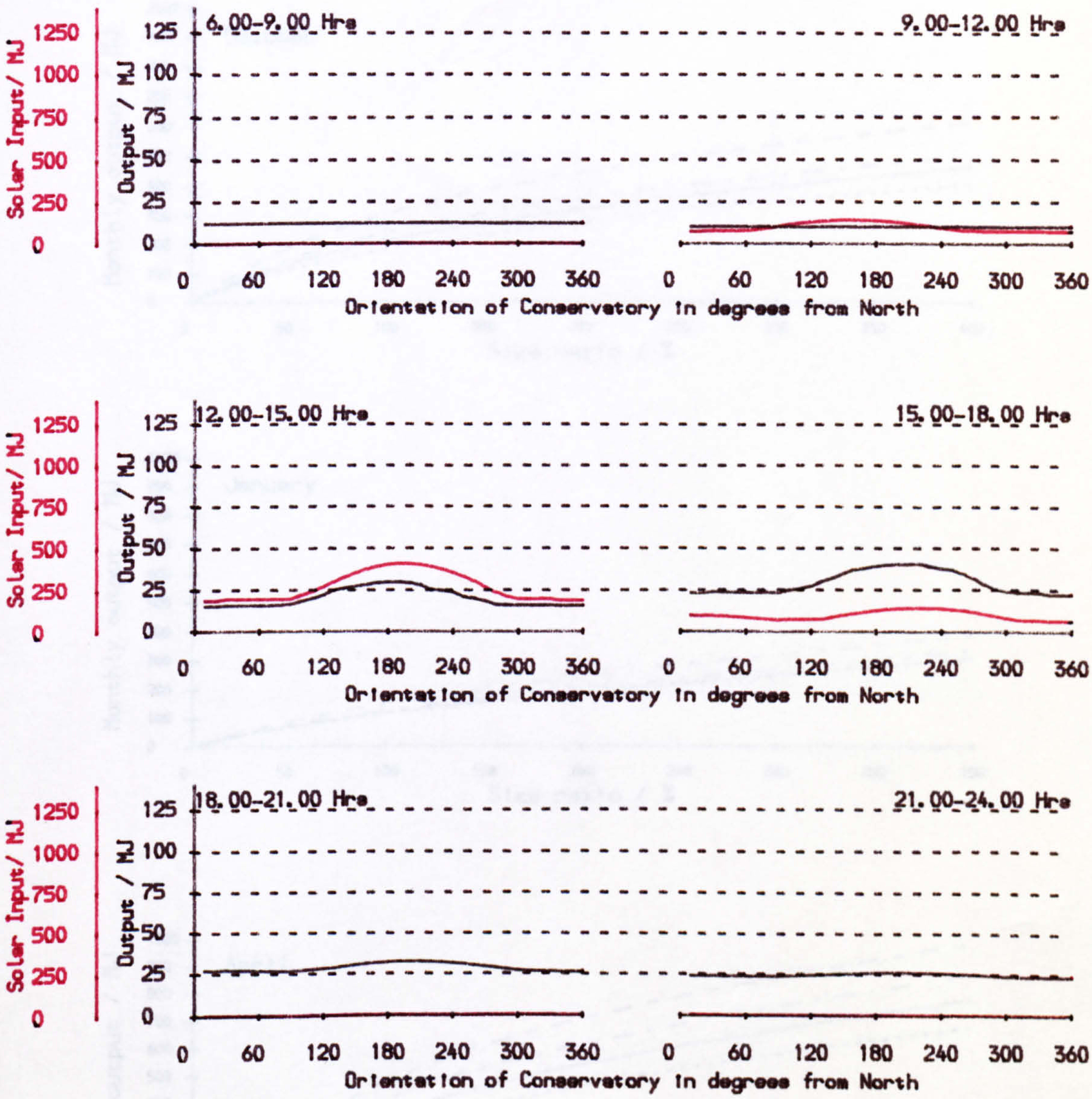
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : November

Fig 7.8

Kew weather data 1963



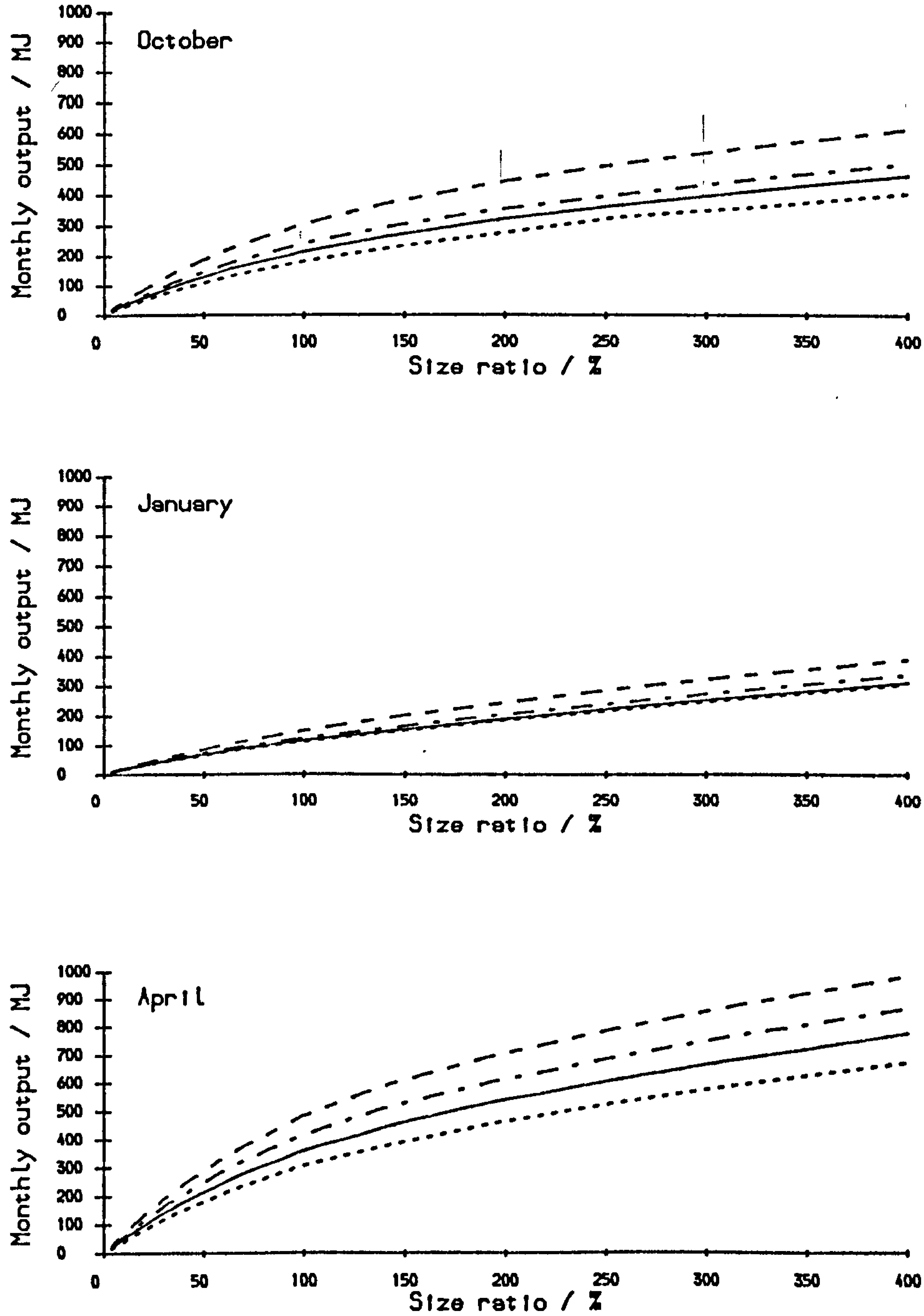
MODELLED CONSERVATORY OUTPUT WITH VARYING ORIENTATION

Total monthly output for three hour intervals in MJ/month. Corresponding total solar input for the same period is shown.

Month : December

Fig 7.9

Kew weather data 1963



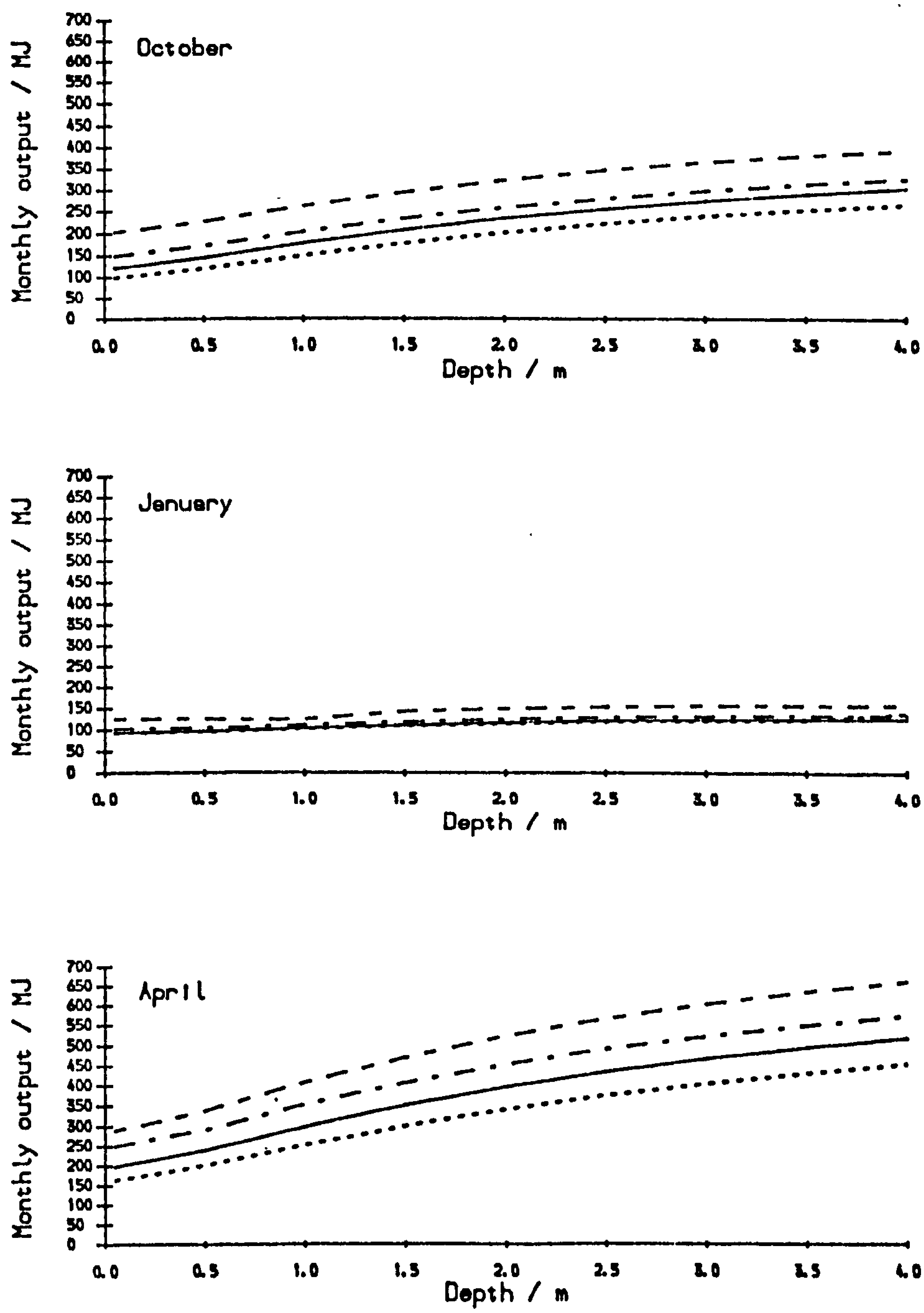
VARIATION OF OUTPUT WITH AREA OF CONSERVATORY

The shape of the conservatory remains constant with all dimensions varying proportionately.
100% = floor: 4.5 m , wall: 8.4 m

1963 Kew weather data

Orientation
——— East
– – – South
— · — West
······ North

Figure (7.10)



VARIATION OF OUTPUT WITH DEPTH OF CONSERVATORY

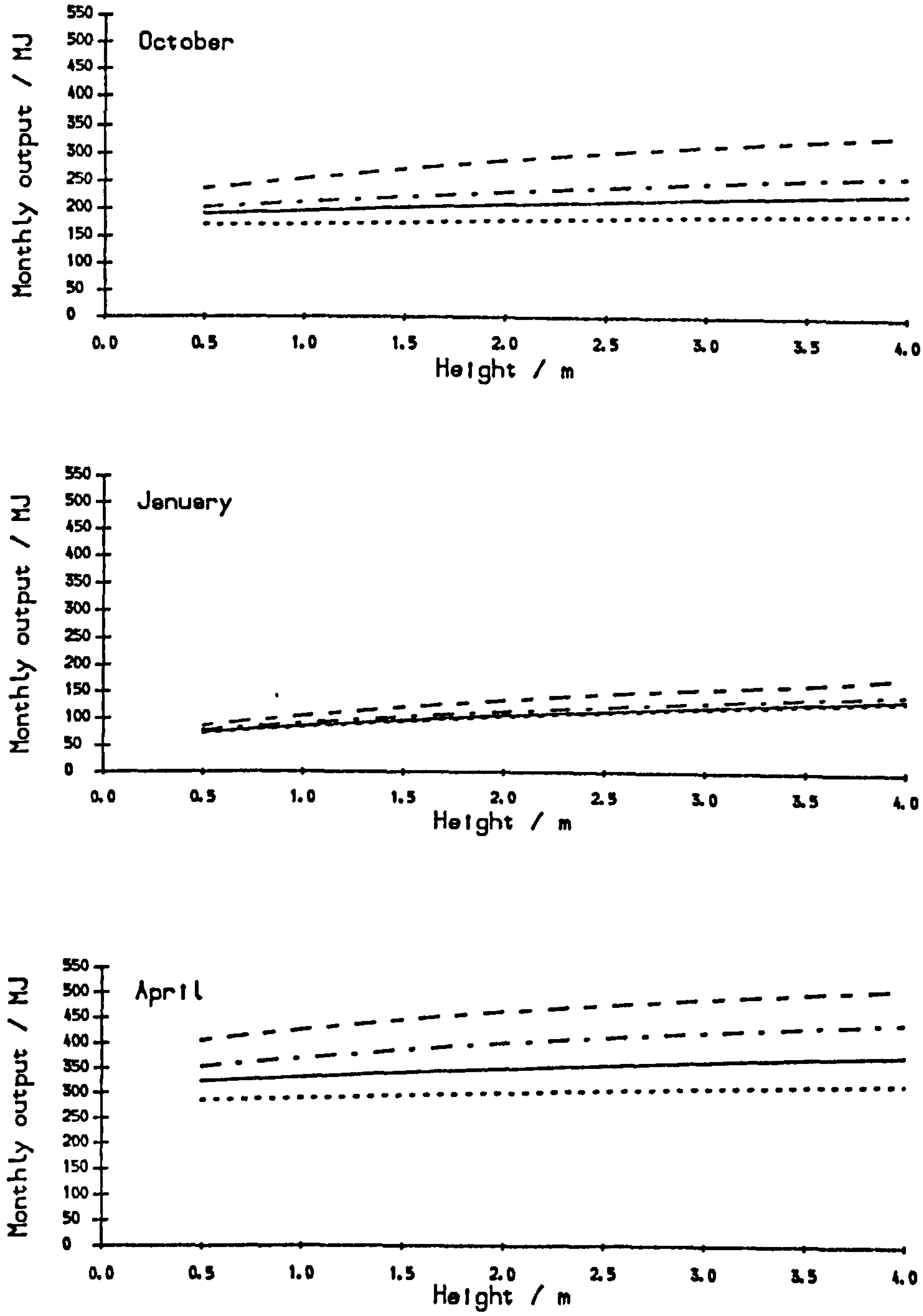
The wall area of the conservatory remains constant at 2.8 m height and 3 m width with the depth varying.

Orientation
——— East
– – – South
— · — West
······ North

1963 Kew weather data

Figure (7.11)

The depth of the conservatory is unimportant in mid-heating season



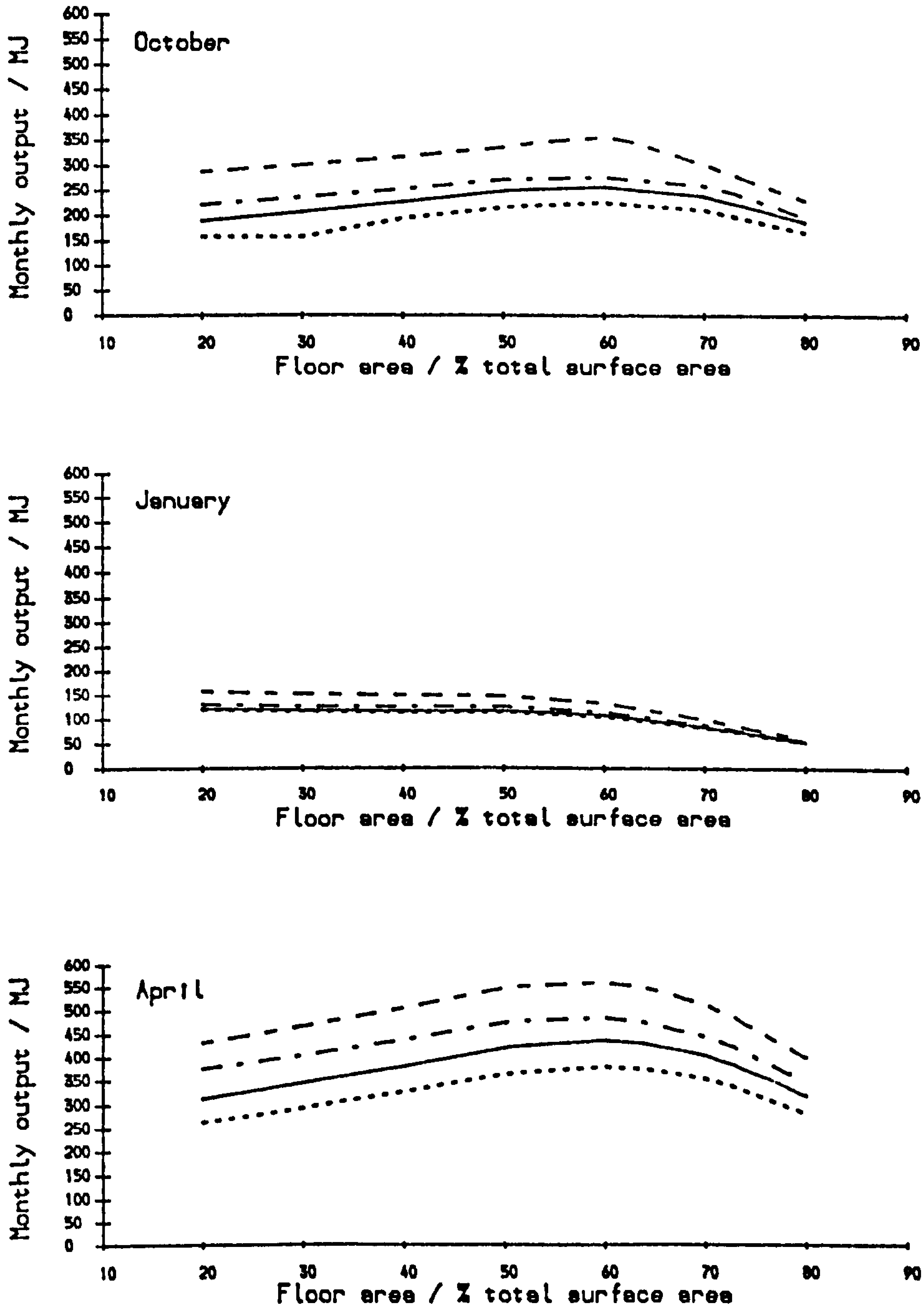
VARIATION OF OUTPUT WITH HEIGHT OF CONSERVATORY

The floor area of the conservatory remains constant at 1.5 m depth and 3 m width with the height varying.

1963 Kew weather data

Orientation
——— East
– – – South
– · – West
······ North

Figure (7.12)



VARIATION OF OUTPUT WITH SHAPE OF CONSERVATORY

The total floor and wall area of the conservatory remains constant with the proportion of the two varying
Total surface area : 13.0 m
1963 Kew weather data

Orientation
——— East
– – – South
— · — West
······ North

Figure (7.13)

Floor area is shown as a percentage of the total surface area.

CHAPTER 8 THE CONCRETE FLOOR SLAB

8.1 Introduction

The benefits of an upper concrete floor as a heat store are many, in particular the loss of any heat by the inefficiency of the slab is to the house and not elsewhere. Additionally it should be possible to retrieve heat from the slab when desired by passing cool air through holes customarily formed through the slab. The literature from many precast floor manufacturers was obtained and it was decided that the most suitable and commonly available floor was the Bison Drycast Floor. This does not in any way preclude the use of other manufacturers' floors.

It was intended to find the floor's potential for storing heat, the length of time it could store the heat, how easily the heat could be recovered from the floor and the controllability of the store.

8.2 The Test Apparatus

8.2.1 The Floor slab

It was intended to obtain a floor section from Bison in Leeds but this was not possible. Instead, a floor section was cast in the Department. The formwork was made for a slab that would be as similar to the Bison product as possible. Its length was 3.0m. This was decided primarily by the size of the room where the tests were to take place. The slab was 400mm wide by 110mm deep with three similar circular ducts of 50mm diameter at 100mm centres along its length. The holes were made using scaffolding poles of 50mm external diameter fixed within the formwork. They were cleaned and greased before casting and removed three hours after the slab was cast.

The design mix of the concrete was to be as similar as possible to that used by Bison which is:

Cement	320	kg/m^3
Water	128	kg/m^3
Fine aggregate	658	kg/m^3
Coarse aggregate	1294	kg/m^3
	2400	kg/m^3

In addition it was intended to use a super-plasticiser. This mix however was still too dry for working within the confines of a small formwork, even with the inclusion of a super plasticiser. The mix was therefore altered to:

Cement	316 kg/m^3
Water	158 kg/m^3
Fine aggregate	649 kg/m^3
Coarse aggregate	1277 kg/m^3
	2400 kg/m^3

A super plasticiser was still used.

The concrete was cast in situ. Test cubes were made and stored in the same room. Minimum reinforcement of Y6 bars were placed in each corner of the slab to ensure that the slab had sufficient strengh to be handled.

The concrete cubes were tested at 14 days to determine whether the formwork could be removed and further construction continue. The test was carried out according to BS 1881 pt 116(BSI,1983) and the compressive strength of the sample was 62.5 N/mm^2 with a density of 2340 kg/m^3. The formwork was therefore removed after fourteen days.

The compressive strength after 28 days was 66.0 N/mm^2 with a density of 2370 kg/m^3.

The inclusion of thermocouples within the concrete caused some difficulty. It had initially been thought that once the concrete had set, small holes could be drilled and thermocouples placed within. This procedure was eventually rejected owing to technical difficulties, and it was thought that such a procedure would be likely to give unreliable results. It was therefore decided that the thermocouples, which were previously calibrated, should be placed into the formwork before casting.

A steel grid was made of 2mm wire. This was of 25mm centres to which the thermocouples could be attached. This however posed problems of heat conduction by the grid across the slab and heat conduction by the thermocouple wire out of the slab, thus giving a false reading. A solution similar to that described by Chapman (1969) for surface temperature measurement was adopted, that of running the thermocouple wire for a short distance longitudinally through the concrete. The thermocouples were supported with nylon fishing line. Fishing line was discovered to be the most suitable since it is very strong and has a low thermal conductivity. The fishing line was of "10 lb breaking strain", equivalent to 44N of breaking force. The line was stretched from one grid to the next and the thermocouple wire was fixed to the steel grid and along the nylon wire. A section of the concrete and the layout of the wires is shown in fig (8.1).

Five wire grids were placed in the slab. One each at the beginning and the end, the other three at approximately quarterly intervals. The thermocouples were therefore 30mm, 730mm, 1530mm and 2530mm from the entrance to the concrete slab and none was placed at the end of the slab.

8.2.2 Air Distribution

A commercial hair dryer similar to those used by hairdressers was chosen as the combined source of heat and fan.

The volume of air that was required to be delivered by the fan was to be in the range of 0.003 - 0.006 m^3/s i.e. 11 - 22 m^3/h. This corresponds to between one half and one air change per hour for the whole house passing through a full size slab. The heater was required to be able to raise the temperature by up to 30 K. This would need a nett heat input of about 200W. The hair dryer purchased had two settings: 600W and 1200W and a fan rated at 60W. It was not possible to switch the fan on independent of the heater. A small control box was therefore made to allow control of the power to the heater including the possibility of switching the heater off completely. It was now thought that the air temperature could be controlled as required. The airflow was harder to estimate and it was left until the system was running to make any necessary alterations.

The air was distributed by a manifold at the entrance and collected by a manifold at the exit of the slab. Both manifolds were constructed so as to slide precisely over the entrance and exit of the slab for a distance of 75mm. The hair dryer was connected directly to the manifold. A 2mm centre wire grill was placed 80mm from the entrance to the concrete and 220mm from the hair dryer to help distribute the air between the three holes. The exit manifold was also 300 mm long but tapered to a 50mm diameter exit. Thermocouples were placed at the entrance and exit of all the ducts, not only to ascertain the inlet air temperature, but to check whether there was even distibution of air through the three ducts. The three exit air temperatures were always within 0.5 K of each other, suggesting a fairly equal distribution. These thermoucouples had radiation screens of aluminium foil.

8.2.3 Orifice Plate

An orifice plate was chosen to measure the air flow from the system.

A significant problem in its design was the low air flow that was likely to be measured through the piping so that an orifice plate with corner tappings was chosen since this would work at lower airflow and lower Reynolds numbers than any of the other types.

The internal pipe diameter was 2.250 inches i.e. 57.150mm and an orifice plate of internal diameter 40.0mm was made. The orifice plate complied with paragraph 54 of BS1042 (BSI,1964). The overall thickness of the plate was 2.5mm of which 1.5mm on the downstream side was bevelled at 40° to obtain an edge thickness of 1.0mm.

The pressure tappings were machined with great care at an angle of 45° to each side of the plate through a flange cemented to the pipe. The pressure tappings complied with all the requirements of paragraph 55 of BS 1042. A recess was made on both sides of the flange to ensure perfect centring of the plate and made air tight with rubber gaskets.

The flanges were bolted together.

Pressure differences were measured with a Furness Micromanometer which had a full scale reading of 10mm water pressure (98 Pa) and 30%, 10%, 3% and 1% scale readings.

For a square edged orifice plate BS 1042 (BSI,1964) gives

$$Q = 0.01252\ C\ Z\ \varepsilon\ E\ d^2\sqrt{h/\rho} \qquad (8.1)$$

where h is in mm water

Under normal conditions

$Z = 1.08$

$\varepsilon = 0.976$

$\rho = 1.2\ \mathrm{kg/m^3}$

and

$C = 0.602$

$E = 1.147$

hence

$$Q = 13.310\sqrt{h} \quad \mathrm{m^3/h} \qquad (8.2)$$

or

$$Q = 3.697 \times 10^{-3} \sqrt{h} \quad m^3/s \tag{8.3}$$

Normally the airflow was measured at around 2.0mm water pressure equivalent to 0.0052 m^3/s.

8.2.4 Data Logging

It was originally intended to use the Credshire 500 analogue data logger previously used in the Leicester Conservatory which can scan up to 100 channels. The output is sent to a Facit tape punch. The logger was originally purchased in 1977 and had already been sent for repair three times. The tape punch was repaired twice but was thought to have worked perfectly since 1978. The logger failed again and it was decided that it was now beyond repair, hence the logger that was then being used to monitor the conservatory was to be used for monitoring the performance of the slab.

The logger was a Christie CD 248 Data Logger. It has many advantages over the Credshire, not least of which was its reliability. It reads directly in degrees Celcius and has a greater variation of scan times. The output was to E.C.M.A. standard data cassettes as descibed in Chapter 5. However, it had a drawback, in so far that it could only scan a maximum of 32 channels and the test required the monitoring of 50 channels. It was therefore decided to connect the less important channels to a Comark digital thermometer, which required personal readings. Channels connected to the Comark were those that were not expected to vary much after the first hour of the test. These included the inlet air temperature, the room air temperature which remained stable to $\pm$ 1.5 K. Additionally the thermocouples of the first section, those at the very beginning of the slab, were connected to the Comark since these were exepected to reach steady state the quickest. During a pilot test, scans were taken by the logger every 5 or 10 minutes throughout the test, and every 5 minutes by hand for the first hour after switch on and switch off and every half hour during the rest of the time. These results were then interpolated to give 10 minute interval readings. At all times during the half hour scans, the temperature change never exceeded 1 K. Tests were undertaken where the slab was allowed to decay overnight. Then it was not possible to read data by hand hence data for Section 1 were not known. A knowledge of the inlet temperature was not then necessary.

8.2.5 Thermal Box

Figure (8.1A) shows the layout of the test rig.

To monitor the thermal losses from the slab an insulated box was built around the concrete. The slab was supported 210mm from the floor by concrete cubes. Purldeck combined roof decking and insulation manufactured by Coolag was used. This product was chosen primarily for its high resistance to fire which was necessary to comply with Departmental regulations.

Purldeck consists of:

"a closed cell rigid polyurethane foam insulation, faced on one side with a lacquered aluminium foil laminate and a Kraft paper and faced on the other side with 8mm thick exterior grade WBP softwood plywood." (British Board of Agrement,1984)

The sheet size is 2400 x 1200mm with a 50mm foam layer. The great advantage of these boards was that they were self supporting. To save labour, the height of the box was 1200mm.

Where the board contacted the concrete, it was stuck with mastic and tape was fixed over this. Where two boards joined, an additional layer of plywood was fixed.

The thermal conductivity of the foam was given as 0.022 W/mK and that of the plywood as 0.14 W/mK. This gave an overall U-value of 0.40 W/m^2K for the thickness used.

8.3 Test Results

8.3.1 Heat Capacity of the Slab

Should the situation arise in which the concrete floor appeared to have attained a condition in which it could no longer absorb any more heat, the use of an additional store would have to be considered, therefore the floor slab's total heat cpacity was to be investigated.

To examine the floor's potential for storing heat, the hair dryer was to be left permanently on at 1200W until the slab appeared to have reached equilibrium, this was considered to be when the outlet air temperature had stabilised at close to the inlet air temperature.

The test was run with an input temperature of 26 K above the ambient air temperature at a flow rate of 18-20 m^3/h. This input could be attained on perhaps the best solar conditions for up to 3 or 4 hours. Despite this, the slab was heated continuously at this rate for 48 hours. After this time the slab still appeared not to have reached equilibrium.

The overall heat loss of the thermal box was calculated. The total surface area of the box was $15.3m^2$ for a given U-value of 0.40 W/m^2 K. The area of the box in the lower half was $1.43m^2$ with a similar U-value. The area of the concrete floor was $1.2m^2$ and the U-value was estimated at 0.21 W/m^2 K from the IHVE guide (1971). The external temperature for the purpose of the heat loss calculation through the floor was estimated at $7^{o}C$.

This gives an overall heat loss equation of:

$$Q = (dTA_t * 6.18) + (dTA_b \times 0.576) + ((TA_b - 7.0) \times 0.25) \quad (8.4)$$

Table 8.1 shows the gain to the slab (net heat input), the heat output from the slab and the loss through the thermal box.

As mentioned above, the floor had not reached a state of equilibrium as defined above. However, the likely loss from the system increases with time and after twenty hours the fabric loss is equal to the nett gain of the concrete. This suggests that while the floor has a greater capacity for heat reception, it was not possible to determine this precisely. Normally, the slab would be expected to lose heat to its surroundings.

The slab does have adequate storage potential since given external conditions of ten hours continuous heat flow, the slab is still not fully charged.

Fig (8.2) shows isotherms for a longitudinal section of the slab midway between two ducts. All figures are temperature differences from ambient. Warm air is passing right to left. Initially there is a temperature gradient which is particularly steep at the entrance. The slab does not heat evenly but once the slab has warmed at the inlet, the temperature gradient becomes less.

After 12-13 hours the difference remains constant, and the sectional temperatures level, suggesting that the system is now losing heat at the same rate as the nett heat gain but the heat is not being conducted down the slab at a sufficient rate to even the temperatures out.

Figs (8.4) and (8.5) show the spot temperatures between the ducts after 4 hours and 20 hours. The top and bottom temperatures are lower than the core temperatures because of the slab's heat loss. The temperature variation is reasonably cosistent for each of the sections and for different times.

8.3.2 Retrieval of Warm Air

The gross heat input is the rate of air flow multiplied by the density and thermal cap acity of the air multiplied by the temperature difference between the test rooms ambient air temperature and the air temperature as it leaves the the hair dryer. The nett heat input is similar but in this case the temperature difference is that between the air entering the slab and exiting the slab.

The floor slab is to dissipate heat by two means, heat loss from the surface of the slab, and warming of cool air. To examine the slab's behaviour during the latter, the slab was warmed for various times and then cool air was passed through the slab. The increase in temperature air was noted.

The total gross heat input and nett heat input up to the time the heater was switched off was calculated. The nett heat output was calculated from the time that the heater was switched off until the outlet temperature was the same as the inlet air. A percentage efficiency was:

$$\frac{\sum \text{nett heat output} \times 100\,\%}{\sum \text{gross heat input}} \qquad (8.5)$$

Several experiments were conducted with heat inputs, and with varied length of time of heat input. It was impossible to maintain exactly the same heat input but they were in the range of 200 to 240 W.

Figs (8.6) and (8.7) show the results for Test 6 and Test 31, whose inputs were similar but the times of input were different. The gross heat flow and inlet temperature remained constant throughout the heating phase but the outlet temperature increases and the nett heat gain decreases accordingly.

After switching the heater off, the exit air temperature drops immediately since the inlet air temperature has been drastically reduced. The outlet air temperature is now higher than the inlet temperature, as the air is being warmed as it passes through the slab.

The inlet temperature was still however higher than the ambient air temperature due to the heat generated by the fan.

For Test 6, the heat output was barely noticeable but for Test 31 in which the total input was about twice that of Test 6, there was a distinct output for about 5 hours after the heater was switched off.

The output from the slab does not appear to be directly proportional to the input. The total input of various test of the similar output rate were compared to their output rate. The results are shown in Fig(8.8) for both gross and nett input. A line of best fit is included in the graph.

The most significant point is that there appears to be a cut off point beneath which there is no heat output. This corresponds to about 750 kJ for the gross heat input and 600 kJ for the nett heat input. Several tests were undertaken where the gross heat input was restricted to less than 750 kJ and in each case there was only a momment at which the outlet temperature was higher than the inlet temperature, the two temperatures becoming the same.

The threshold that occurs before any output is observed is probably due to the natural storage of the slab and its dissipation of heat by radiation. As warm air enters the slab, the slab warms up and the air subsequently cools down. Until a certain level of heat input is achieved, internal surfaces of the slab will still be cool at the end furthest from the input end. If cool air is now blown through the slab, this will be warmed by the slab only to warm the cool end of the slab, the air thus appearing at the outlet unwarmed. The threshold is the point at which the slab has been warmed sufficiently to ensure warmer surfaces throughout the slab.

A similar range of tests was carried out with a higher input of 240 W - 250 W. The results are shown in Fig (8.9).

The relationship is now almost linear for the gross input v nett output and there is a lower start of about 350 kJ.

The behaviour of the concrete floor as an air warmer is not only dependent upon the heat input but also on its rate. This is because of the rate at which the slab is losing heat from its surface. If the heat is input rapidly the concrete has less chance to dissipate this heat by natural losses and is therefore a more efficient short term heat store.

When the slab is left stagnant for between one and two hours after heating, ie. neither cool or warm air is passed through the slab, the subsequent output once the fan alone is switched on is higher than should the fan alone have been switched on directly after heating.

Fig (8.10) shows the typical results for Test 18 in which the heater was on for two hours and fifty minutes at about 230 W, then switched off completely for about fifty minutes. The fan was then switched on to blow cool air through the slab. The nett output from the slab was 215 kJ but had cool air been switched on immediately the output would have been expected to be in the range of 40 kJ - 80 kJ.

A similar behaviour was noticed if the heat levels were varied as in Test 16, Fig (8.11). Had the heat been supplied steadily for a shorter time the nett output would have been expected to be 125 kJ - 170 kJ instead of the 225 kJ measured.

However, if the period of off time is substancially increased as in Test 37, Fig (8.12), the output is reduced. had the total heat input been continuous, the output would have been 60 kJ - 90 kJ instead of 16 kJ.

8.3.3 Surface Heat Loss from the Slab

In order to estimate the surface heat loss from the slab, thermocouples were placed on the surface of the concrete slab, top and bottom, and on all the internal surfaces of the box and floor surrounding the slab. The temperature of the air above and beneath the slab was also monitored.

In the radiation loss calculation, the emisivity of the concrete and the floor was taken as 0.9 and that of the aluminium coating on the insulation board as 0.2 (C.I.B.S.E.,1981).

O'Callaghan (1978a) shows that the radiant heat exchange between two surfaces is equivalent to:

$$A\mathcal{F}_{1\text{-}2} = \left[\frac{1}{A_1}\left(\frac{1}{\epsilon_1} - 1\right) + \frac{1}{A_2}\left(\frac{1}{\epsilon_2} - 1\right) + \frac{1}{A_1 F_{12}}\right] \qquad (8.10)$$

The shape factor F was calculated using the program SHAPE04 FORTRAN described in Chapter 5.

O'Callaghan also shows (1978a) that for typical temperatures in the range of about 270 K to about 320 K, that

$$Q = 5.8\mathcal{F}A(T_1 - T_2) \qquad (8.11)$$

The overall loss by radiation was thus calculated.

The heat loss by convection was calculated using the equation (O'Callghan,1971b) for horizontal enclosed spaces:

$$Nu = 0.21\ (GrPr)^{0.25} \tag{8.12}$$

This equation is applicable for Grasshof numbers of between 10^4 and 3.2×10^5 which was always the case.

Given :

$$h_C = Nu\ K_f / L \tag{8.13}$$

and

$$Q_C = h_C A\ (dT) \tag{8.14}$$

for the known circumstances Q becomes:

$$Q_{ctop} = 1.2 \times 0.052 \times (dT)^{1.25} \tag{8.15}$$

$$Q_{cbot} = 1.2 \times 0.074 \times (dT)^{1.25} \tag{8.16}$$

The radiation loss and convection loss were calculated for each time interval and plotted against time.

Figs (8.13,8.14) show the conditions for Tests 85 and 88 and figs (8.15, 8.16) show the radiation and convection losses in the form of a block diagram.

Test 85 had cool air blown through the slab after the heating period whilst Test 88 was left to cool without cool air being passed through it.

These results are typical of the behaviour that was found which varied very little from test to test. In all cases the losses by radiation are far greater than the convection losses which are negligible. After switching the heater off there is a fairly rapid decline in the rate of heat losses but it then levels. In all tests the minimum heat loss after 12 hours was 15W, equivalent to 9.4 W/m^2 or about 400W for a normal sized floor.

8.3.4 Variation of air flow

The fan in a warm air heating unit has until now operated at a constant speed determined primarily by the characteristics of the fan It was attempted to maintain air flows through the ducts similar to those that would be found in a complete system. However the speed at which the air flows through the ducts has a great affect upon the local heat transfer coefficients between the air and the concrete ducts.

In the future it will be possible to obtain variable speed fans such as used in the 'ModAir Flow' system developed by Johnson and Starley. It may be possible to improve the efficiency of the slab with variable speeds, this will require a more sophisticated control system than was originally envisaged (see Chap 9) and is therefore outside the scope of this work.

The majority of the experiments were done with air flow rates of about 0.005 m^3/s which corresponds to an air speed of about 0.85 m/s. At this speed the Reynolds number is about 3000 corresponding to transitional flow. When the flow rate was reduced to between 0.0025 m^3/s and 0.004 m^3/s the behaviour of the floor slab altered considerably. Its ability to give out heat once the heater had been switched off was considerably reduced, the output usually being too small to measure. These air flow rates correspond to Reynold numbers between 1500 and 2200 which is laminar suggesting the low heat transfer coefficients found.

It was not possible to increase the rate of flow of air as the fan was operating at its maximum speed.

Should a higher air speed be obtained, it is likely that higher heat transfer coefficients would have been achieved and greater storage and retrieval of heat would have been possible.

8.4 Summary and Conclusions

8.4.1 The heat loss from a first floor slab store is almost totally to the inside of the house.

8.4.2 A trial floor slab was cast and monitored.

8.4.3 The slab had a greater storage capacity than was necessary. There is no need to consider the inclusion of an additional store at ground floor level.

8.4.4 It is possible to recover heat from the slab in the form of prewarmed air by passing cold air through the slab. There is a minimum to which the slab must be charged for this to occur. This is reduced if the rate of charging is increased.

8.4.5 The higher the heat output, the greater the efficiency of the concrete slab is as a store.

8.4.6 Charging is not affected by switching off the fan and heater. Provided the periods of charging are not less than half an hour, this improves the efficiency of the slab.

8.4.7 The slab may be left for several hours after charging before heat recovery without a significant loss of output.

8.4.8 The most significant mode of heat loss is by radiation which continues steadily for over twelve hours.

8.4.9 Reducing the size of the holes through the concrete or their frequency will increase air speed. This may ensure turbulent flow through the ducts and thus produce higher heat transfer coefficients. The reader is refered to Appendix A.

3 Bonace Gas →

PLATE 8.1 Concrete floor test

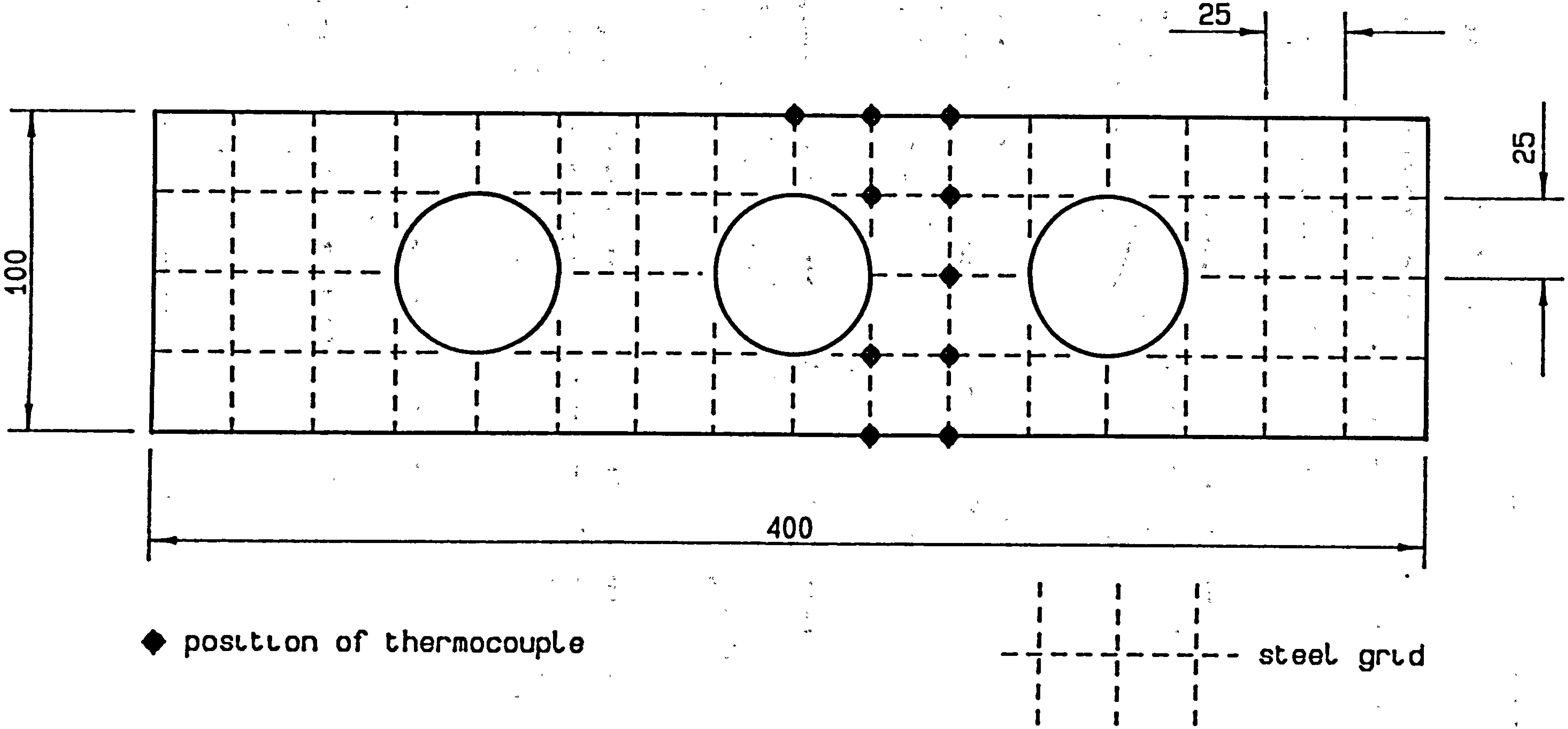
Layout of concrete slab test

Figure (8.1A)

Table 8.1 Gain to slab, output from slab and heat loss from the thermal box

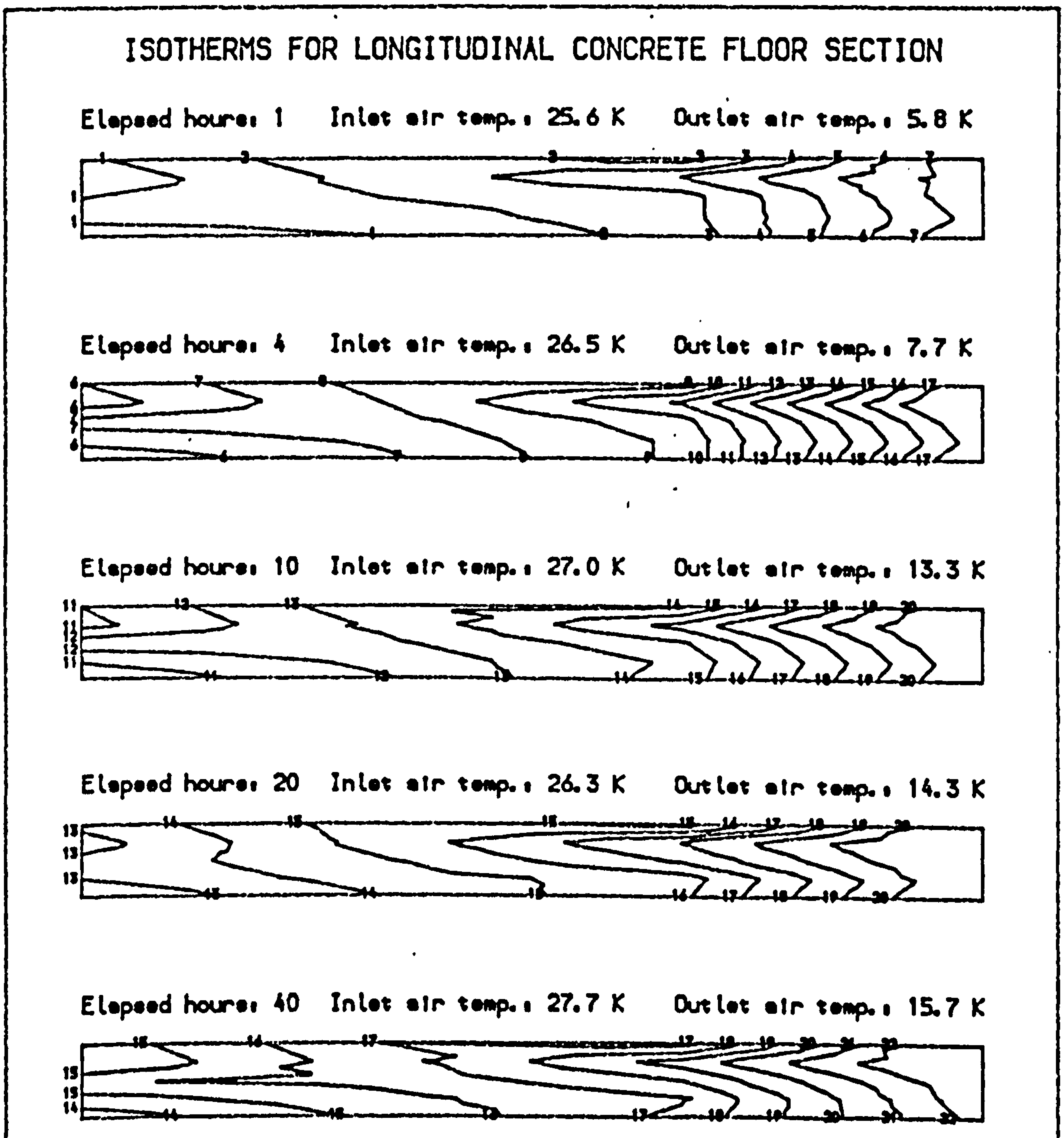
Elapsed time h	Flow $m^3/s \times 10^{-3}$	Net Heat W	Heat Output W	Heat Los W
1	4.9	113	36	12
4	5.2	98	59	40
10	5.3	83	80	63
20	5.2	72	85	72

SECTION THROUGH CONCRETE SLAB



all dimensions in millimetres

FIG (8.1)



Shows the temperature distribution in the centre of the slab

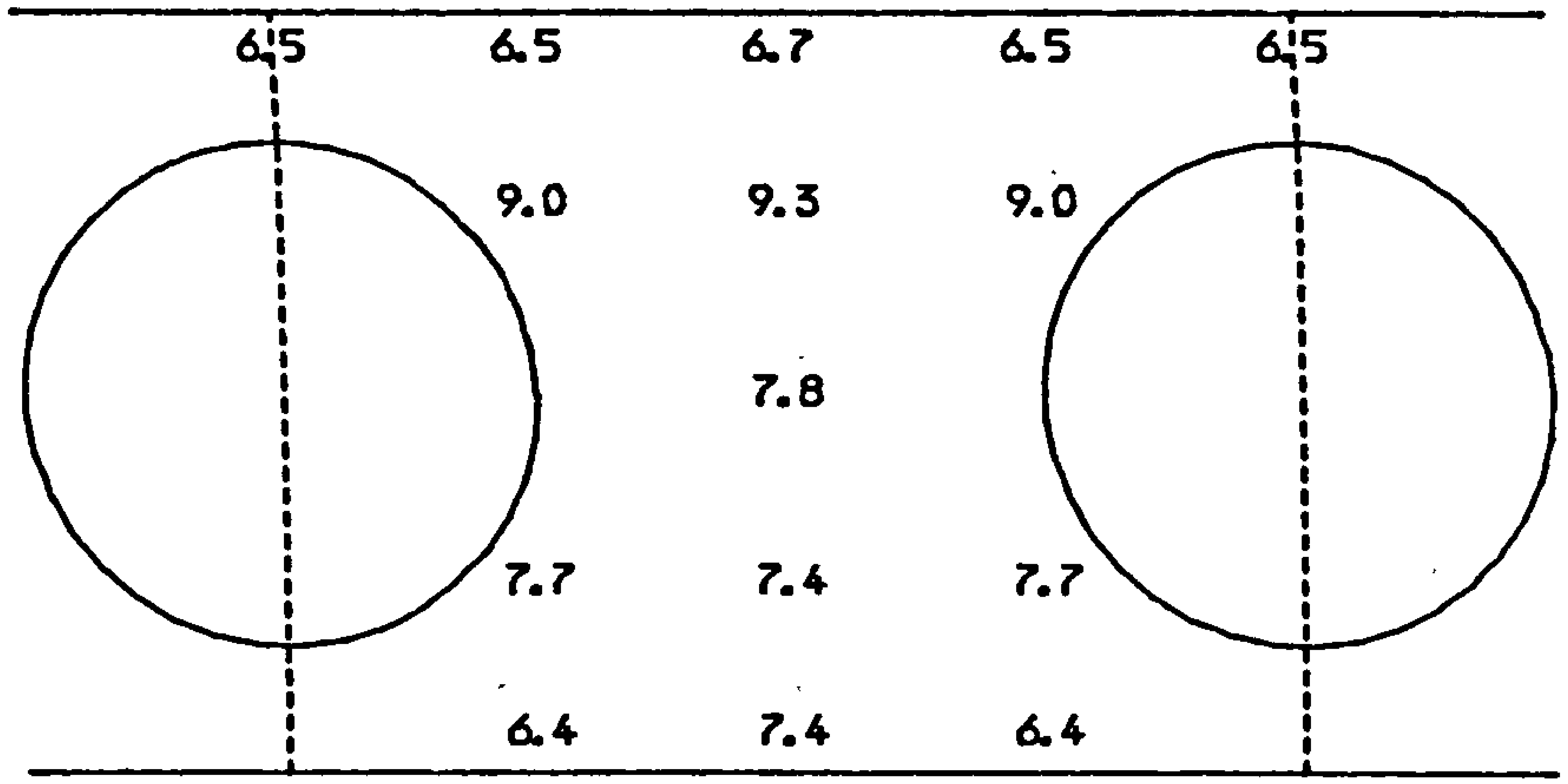
All temperatures are differences from ambient

Note the reduction in temperature gradient with time

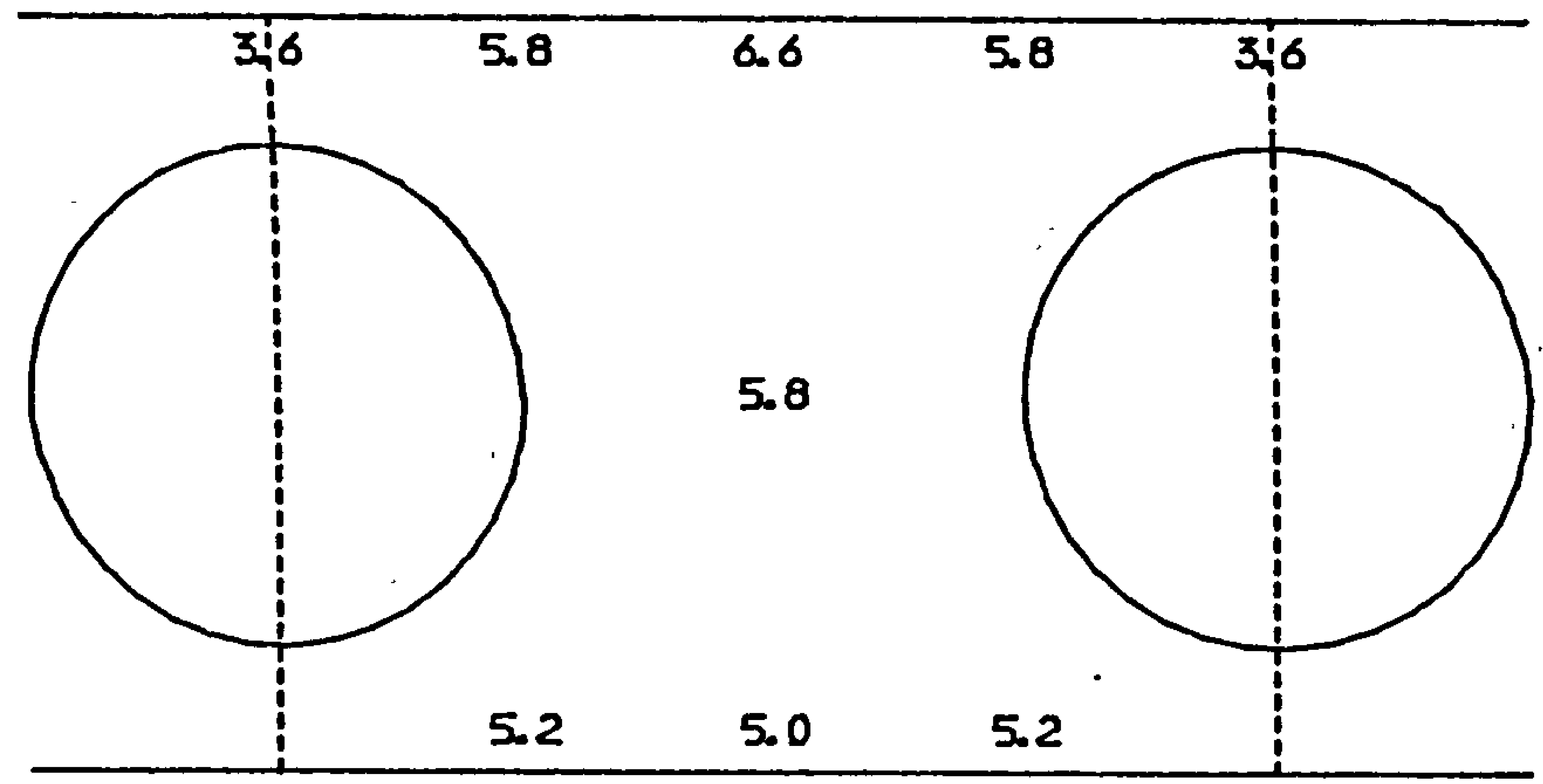
Air flow from right to left

48 hour continuous test

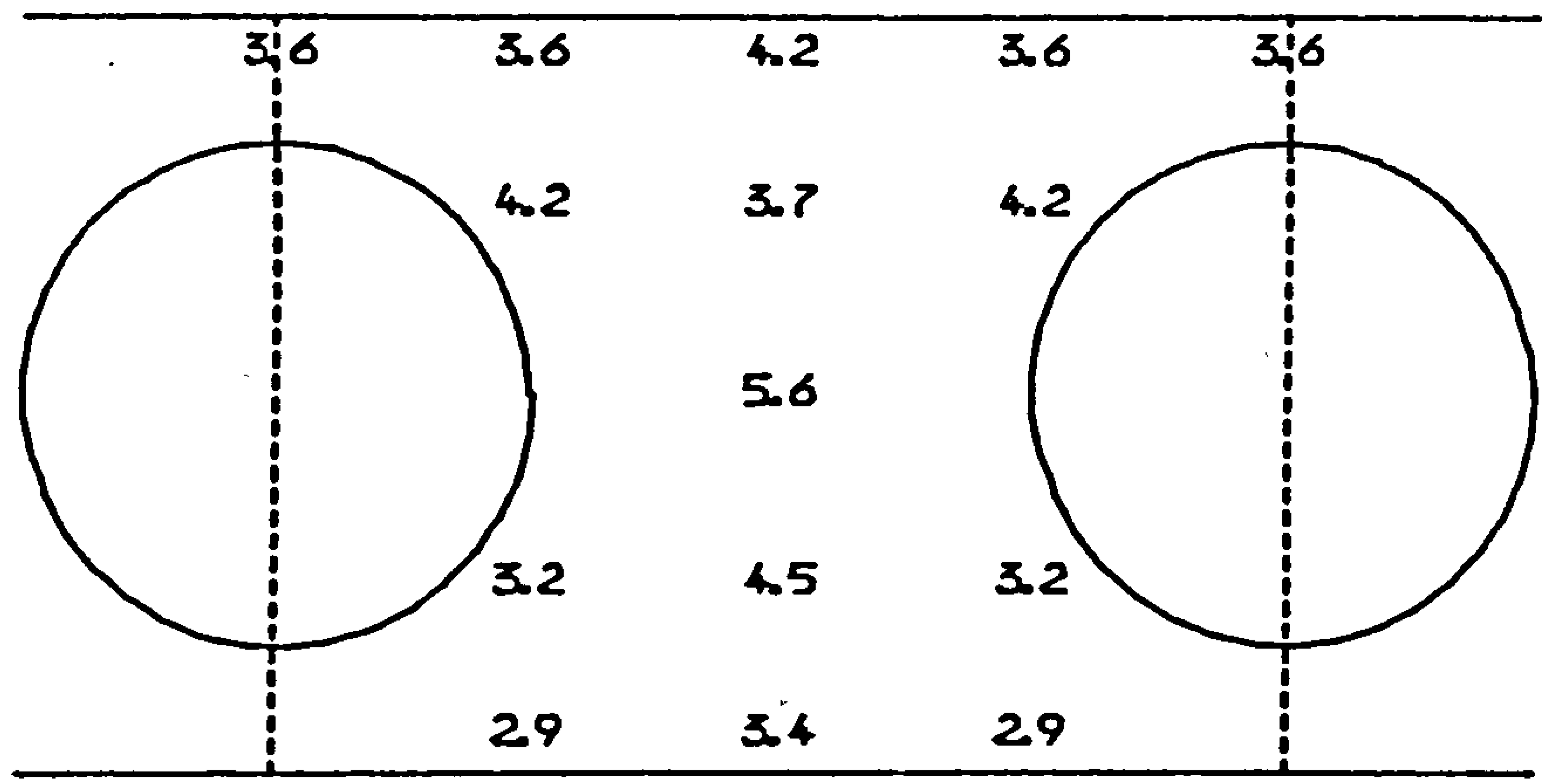
Figure (8.2)



SECTION 2



SECTION 3

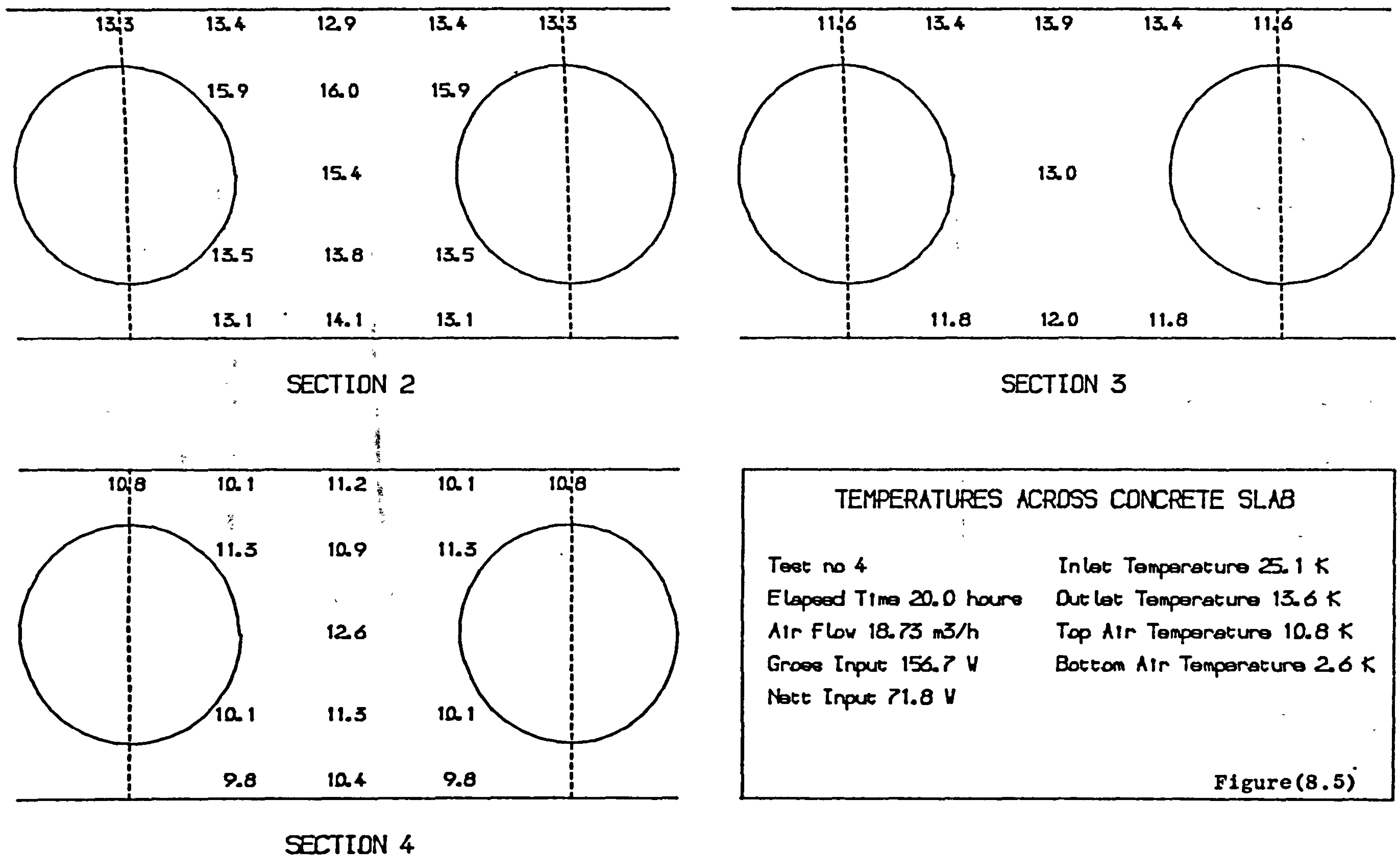


SECTION 4

TEMPERATURES ACROSS CONCRETE SLAB

Test no 4	Inlet Temperature 25.0 K
Elapsed Time 4.0 hours	Outlet Temperature 9.3 K
Air Flow 18.82 m3/h	Top Air Temperature 5.8 K
Gross Input 156.9 W	Bottom Air Temperature-0.5 K
Nett Input 98.5 W	

Figure(8.4)


13.3
13.4
12.9
13.4
13.3
15.9
16.0
15.9
15.4
13.5
13.8
13.5
13.1
14.1
13.1
SECTION 2
11.6
13.4
13.9
13.4
11.6
13.0
11.8
12.0
11.8
SECTION 3
10.8
10.1
11.2
10.1
10.8
11.3
10.9
11.3
12.6
10.1
11.3
10.1
9.8
10.4
9.8
SECTION 4
TEMPERATURES ACROSS CONCRETE SLAB
Test no 4
Elapsed Time 20.0 hours
Air Flow 18.73 m3/h
Gross Input 156.7 W
Natt Input 71.8 W
Inlet Temperature 25.1 K
Outlet Temperature 13.6 K
Top Air Temperature 10.8 K
Bottom Air Temperature 2.6 K

Figure(8.5)

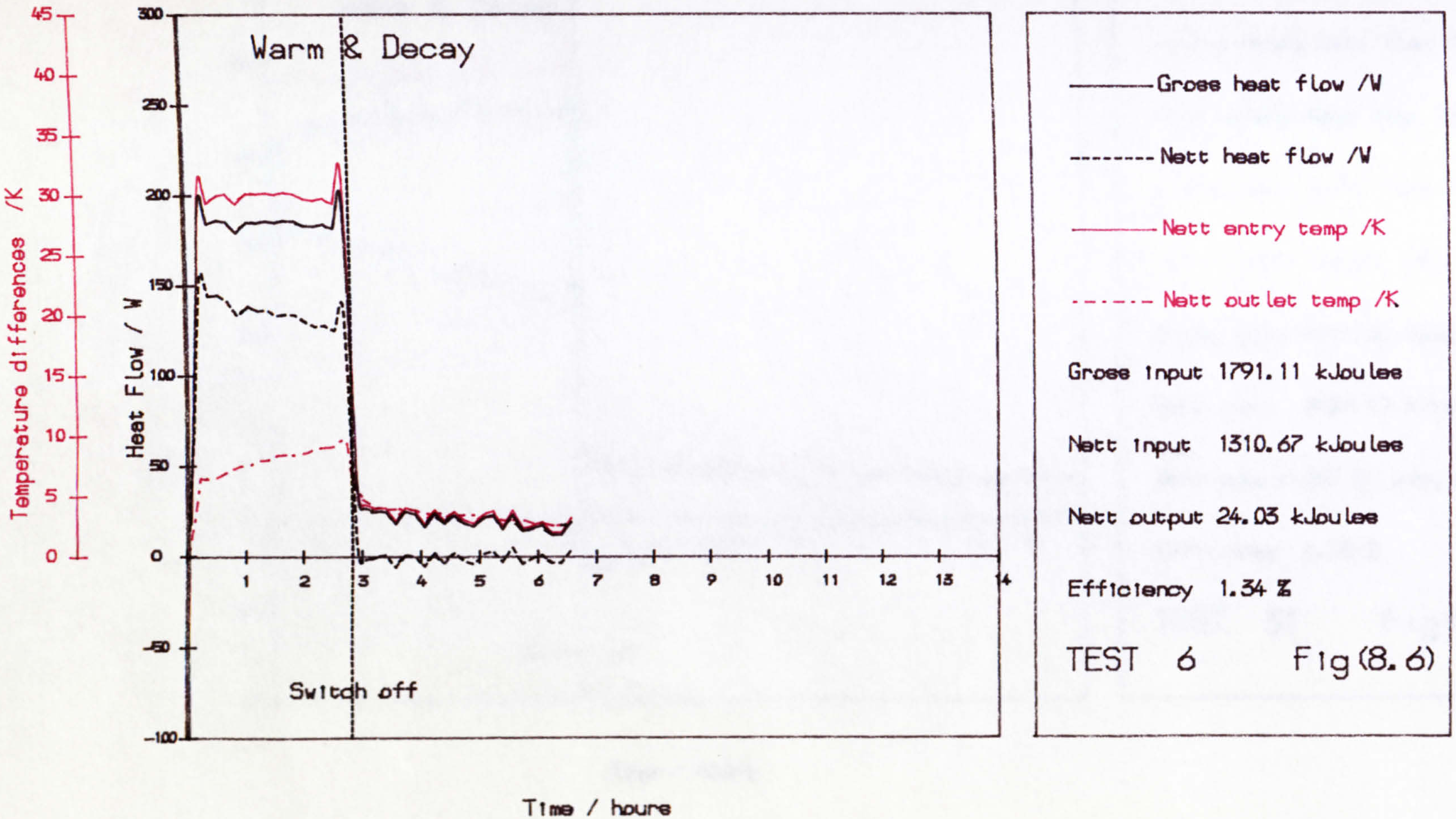
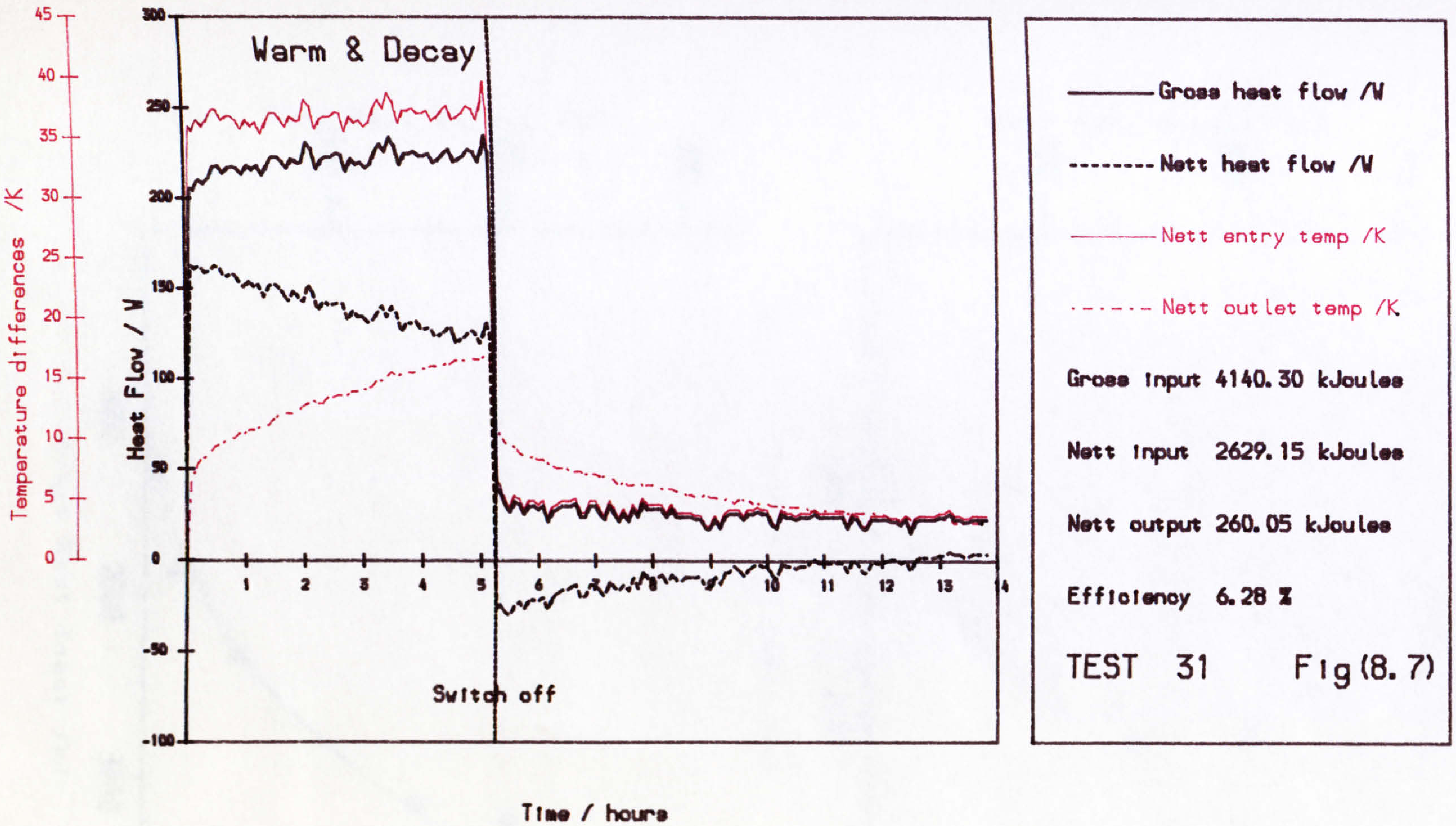


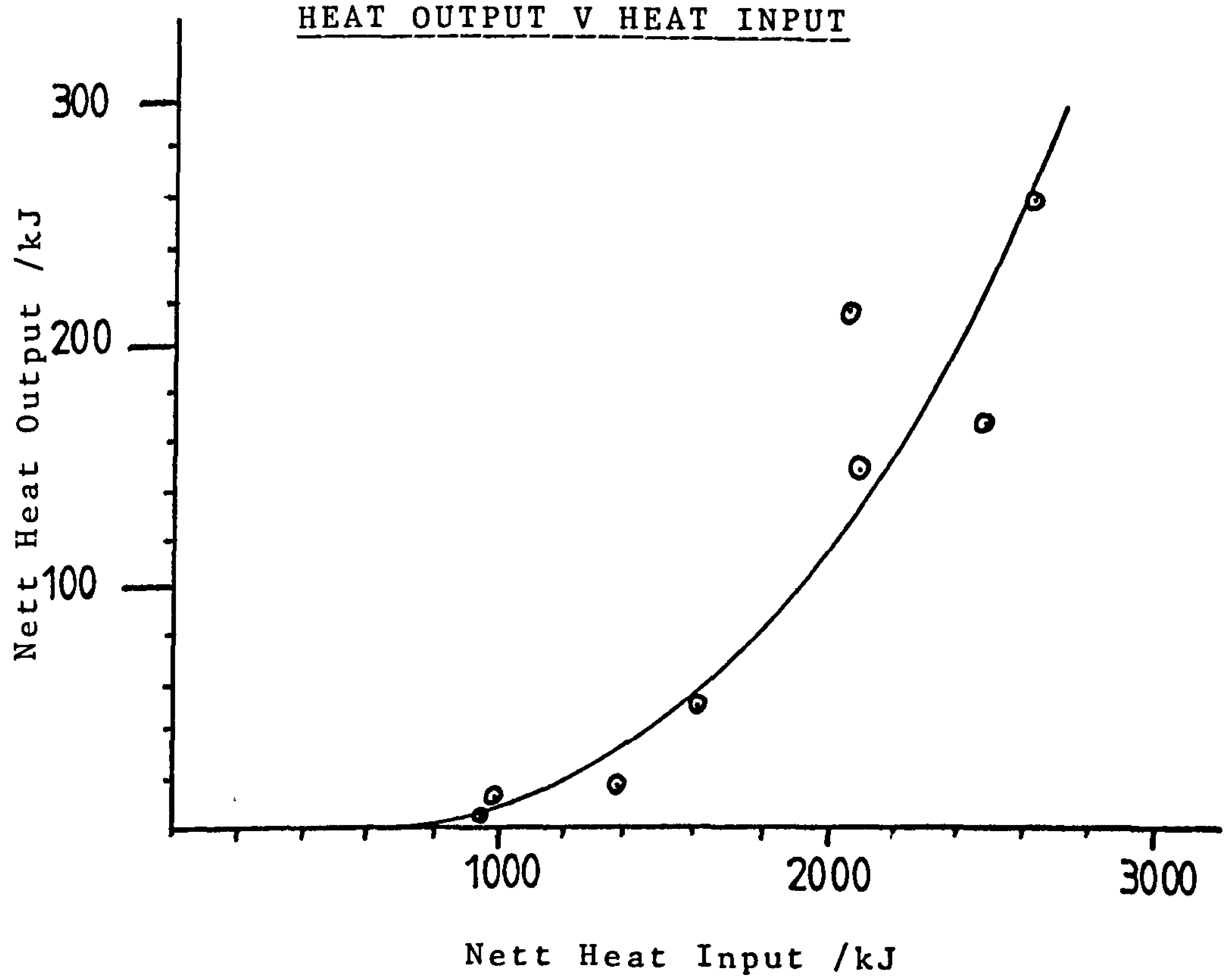
Fig (8.6)

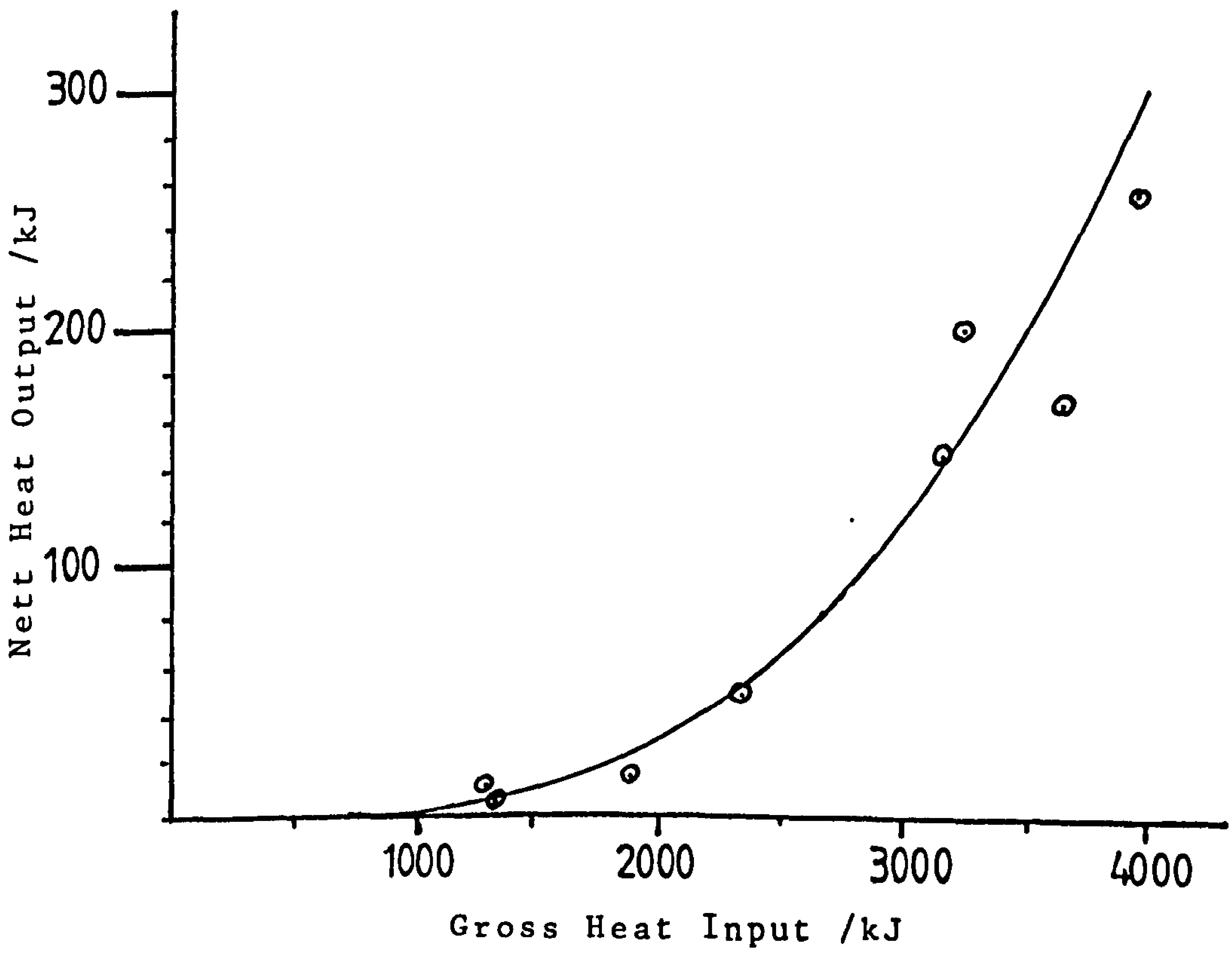
Shows negligible output from the slab after switch off



Shows a measurable output from the slab with longer input time (Nett heat flow is negative i.e. output)

HEAT OUTPUT V HEAT INPUT





Fig(8.8) LOW INPUT LEVEL

Note: There is a minimum input required before any output is achieved

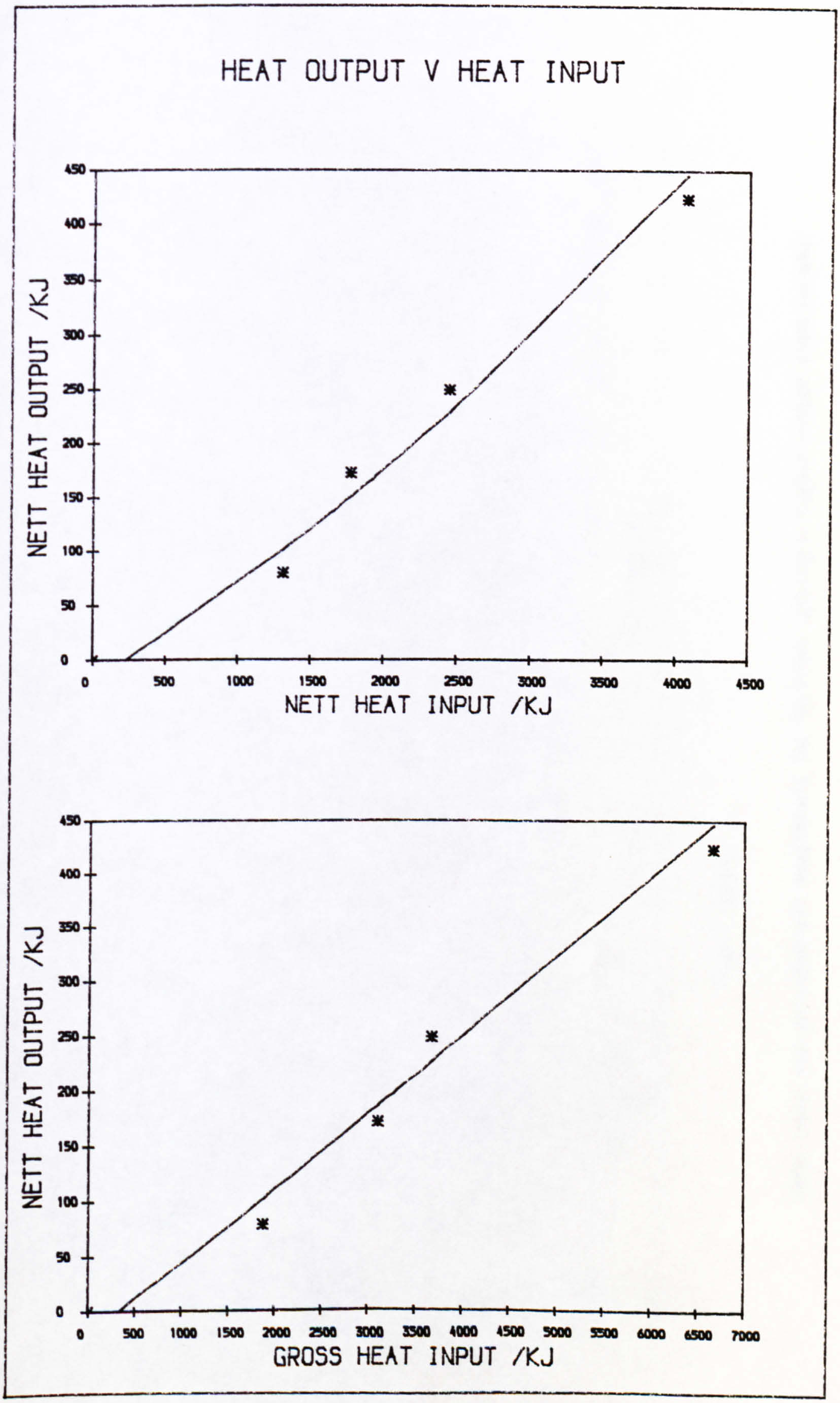
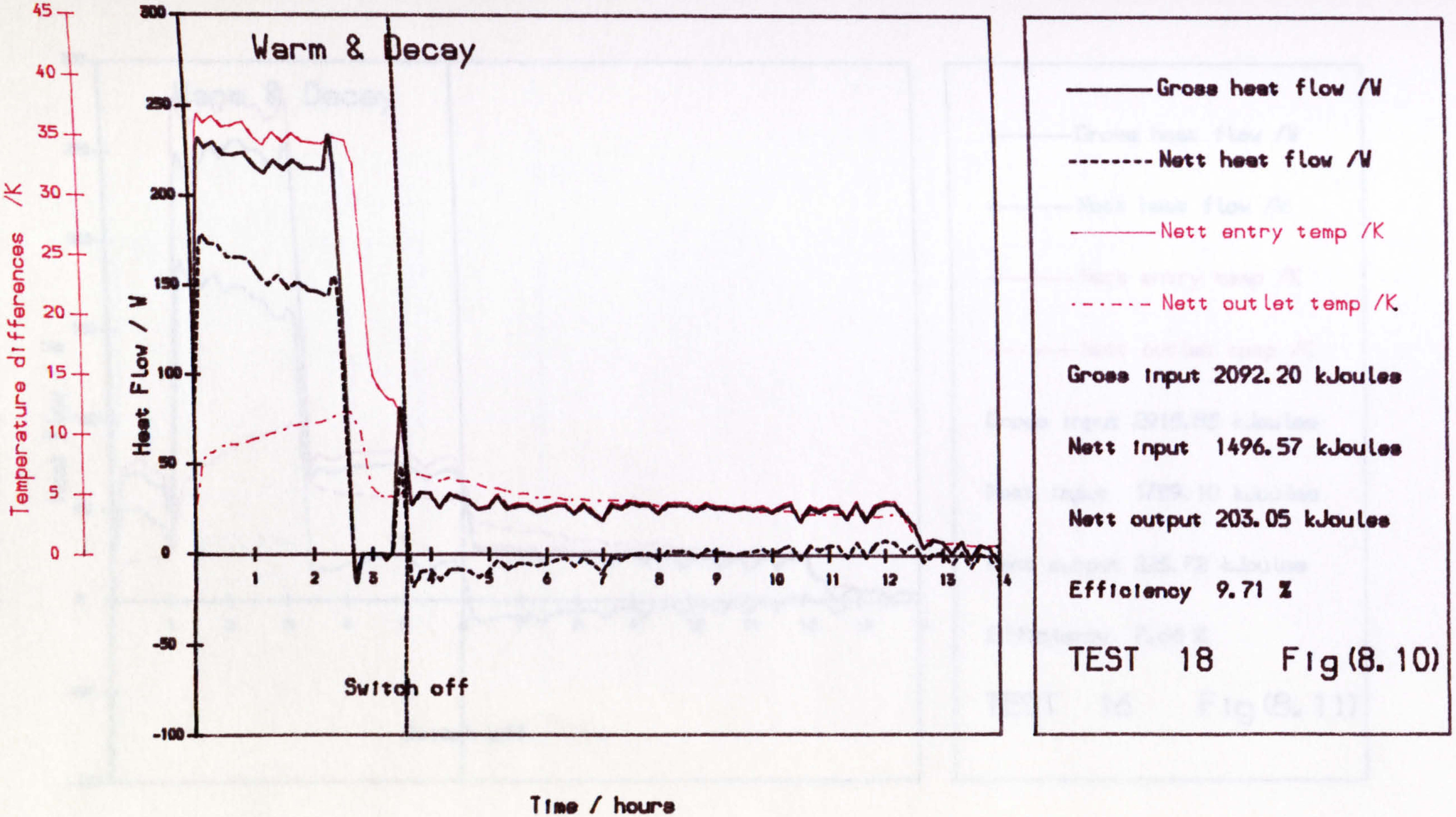
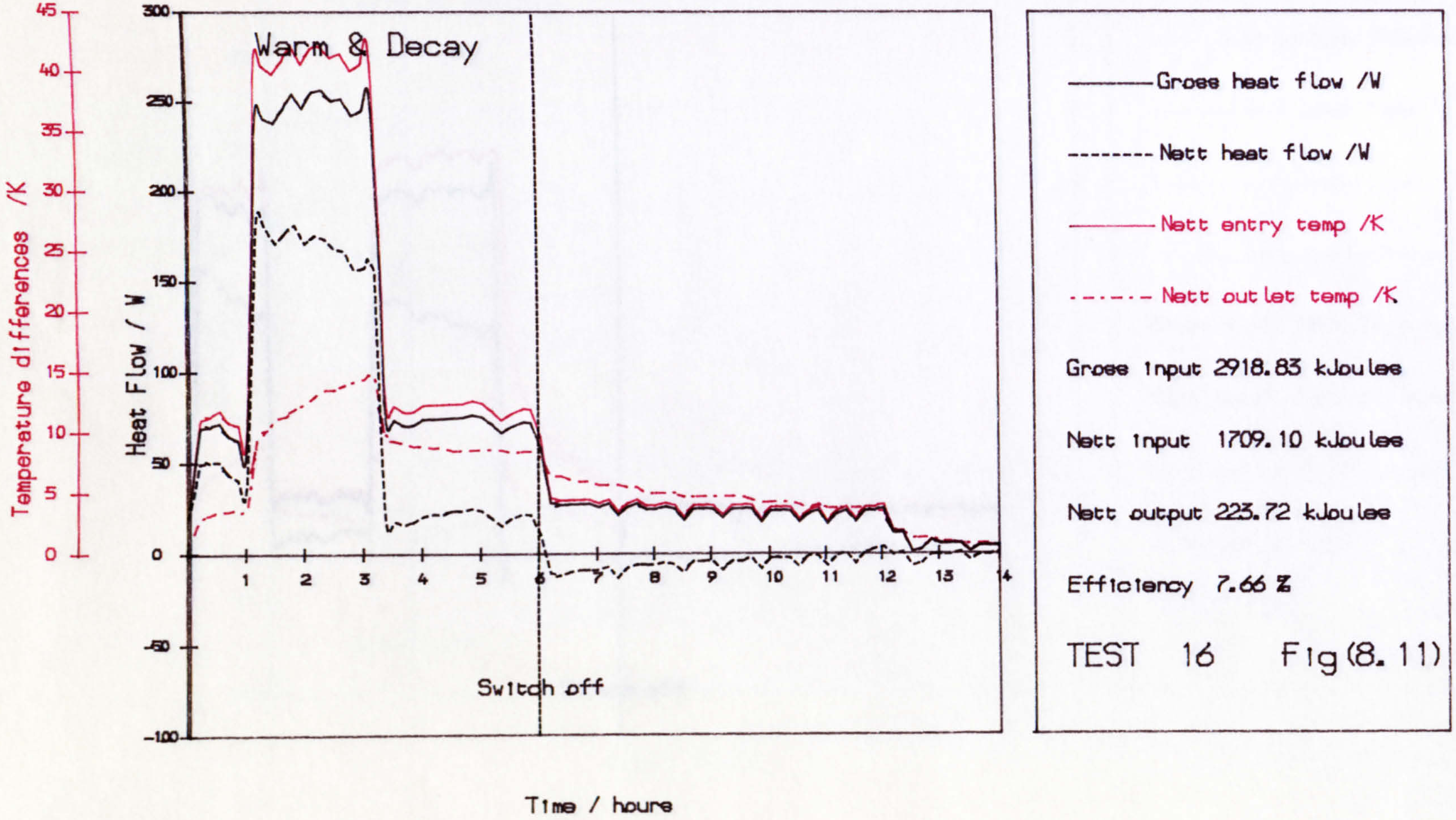


Figure (8.9) Higher input level

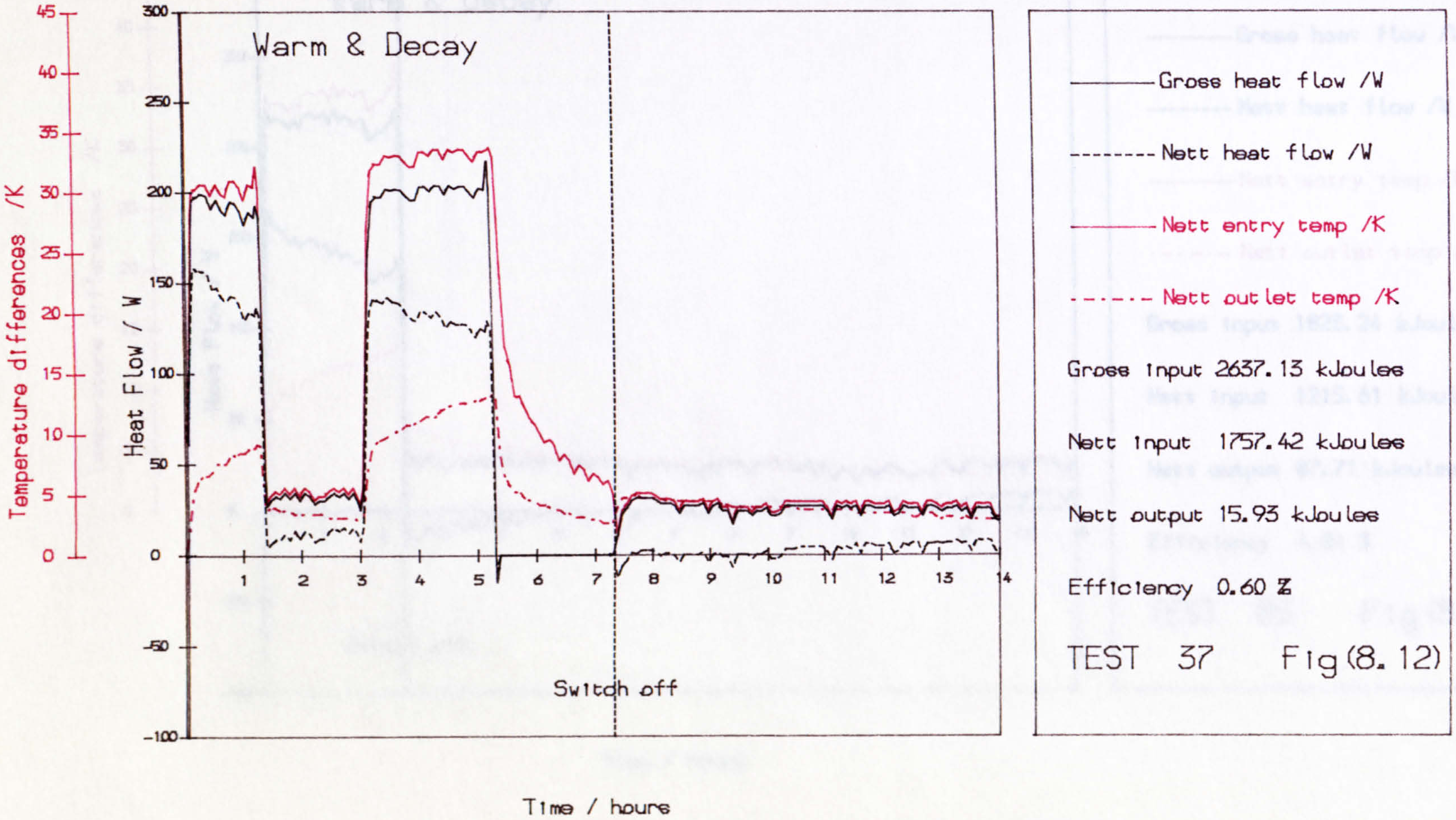
Note: with a higher level of input, the start point for output is lower. The slab is more efficient with higher levels of input.



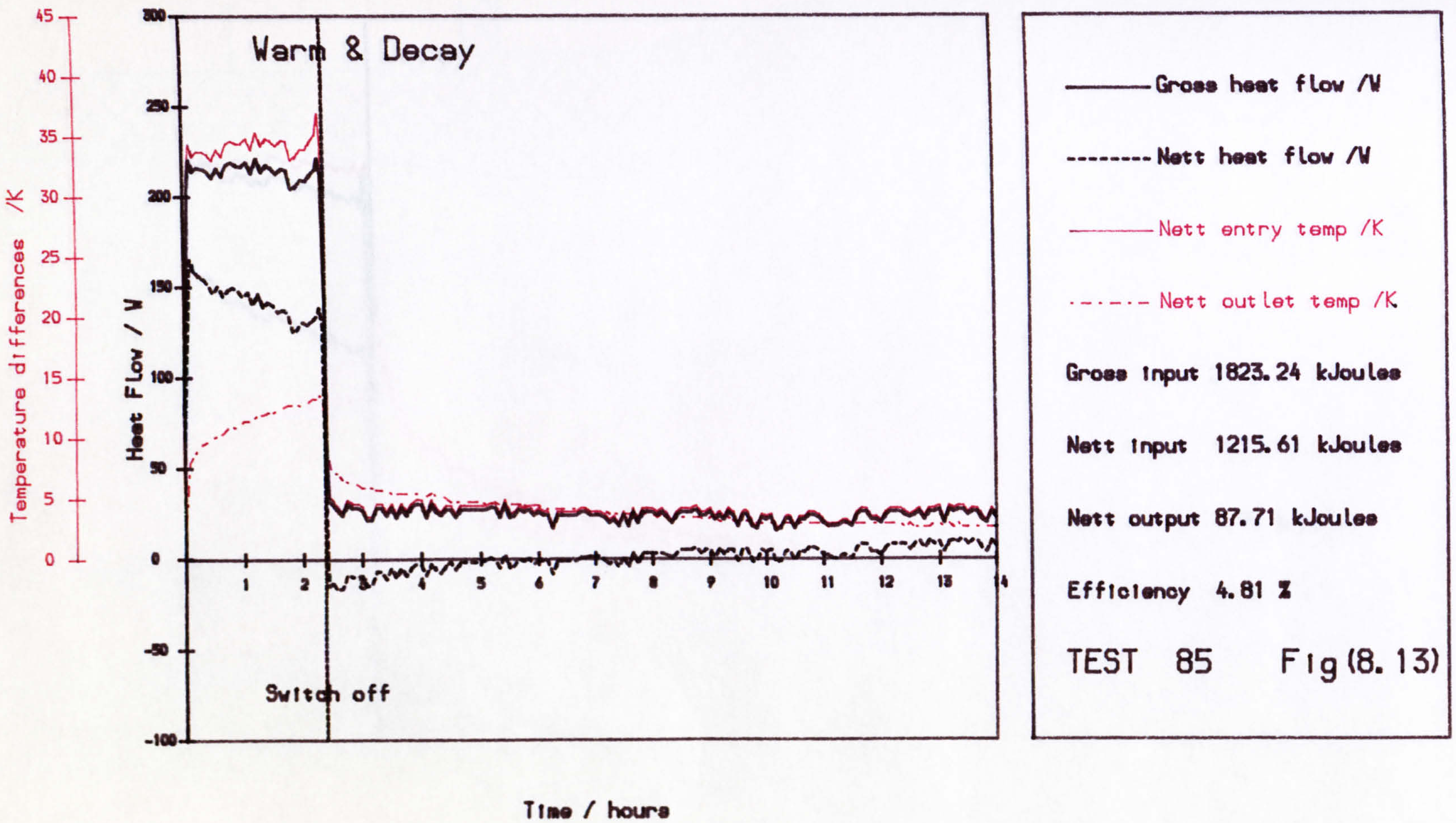
Heat input was switched off completely for 50 mins. giving a higher output than normal



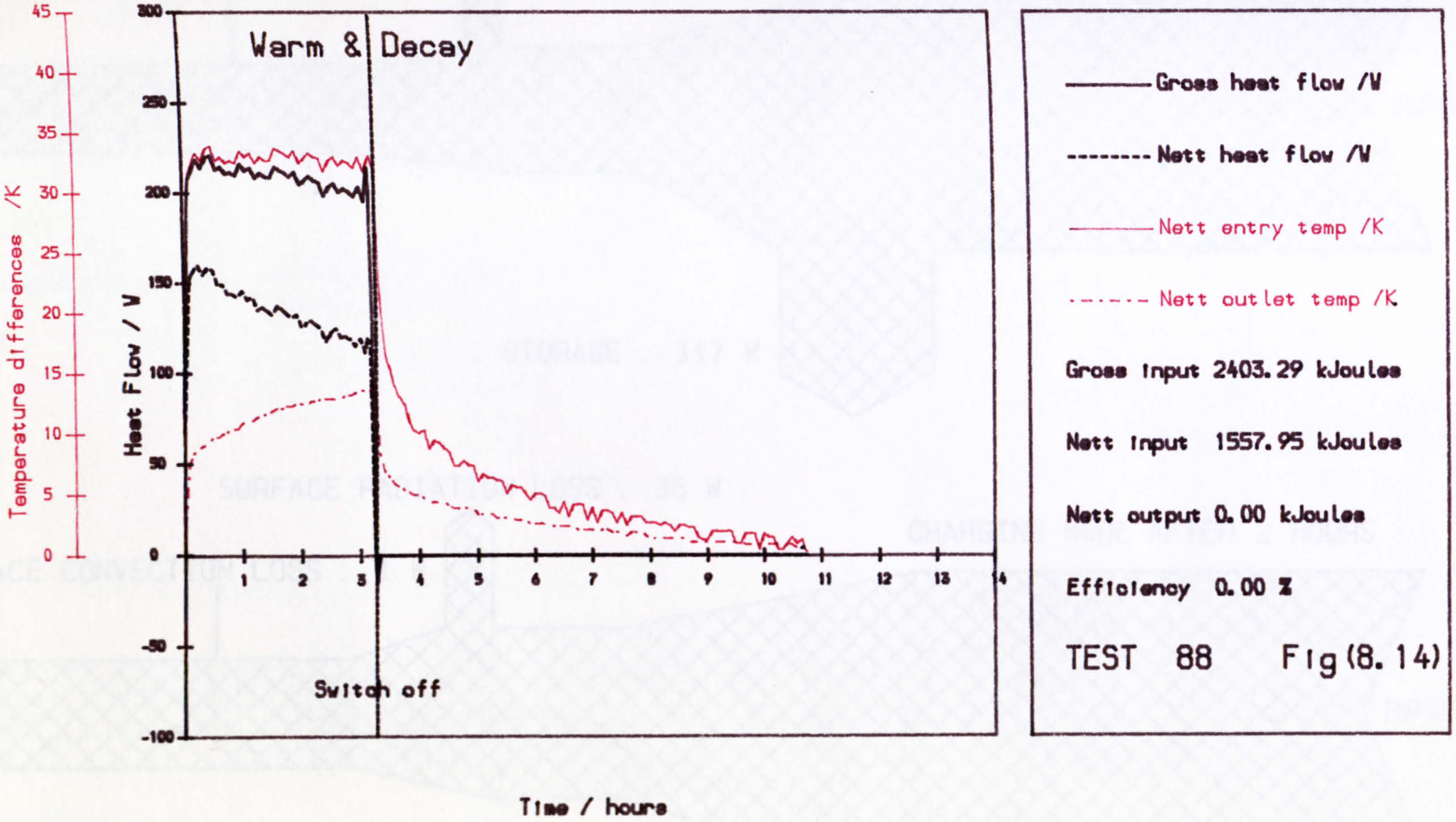
Varying the heat input level produces a higher output than a steady rate of input



A long period of low input and zero input gives poor output (Nett heat flow is negative i.e. output)



A short period of input produces a moderateoutput



A short period of input, then the slab is allowed to decay naturally


CHARGING MODE AFTER 1 HOUR
SURFACE RADIATION LOSS : 27 W
SURFACE CONVECTION LOSS : 1 W
OUTPUT
65 W
INPUT : 210 W
STORAGE : 117 W
CHARGING MODE AFTER 2 HOURS
SURFACE RADIATION LOSS : 36 W
SURFACE CONVECTION LOSS : 1 W
OUTPUT
80 W
INPUT : 210 W
STORAGE : 93 W

Figure (8.16)

HEAT FLOW THROUGH SLAB WHILST DECAYING .

CHAPTER 9 PROPOSED WAKEFIELD HOUSING SYSTEM

9.1 Introduction

It is proposed to build a terrace of houses in Wakefield, West Yorkshire that encompass many of the designs that have been discussed above.

In the design of a whole house system, an attempt has been made to minimize any necessary alterations to any of the 'off the shelf' components that it is proposed to use, whilst remaining within the constraints of the achitect's overall house plan.

The houses were conceived with the passive solar system in mind and much work has gone into their design to facilitate the inclusion of such a system.

9.2 House details

The houses are to be a row of small terrace houses intended for first time buyers in Wakefield. They are similar in many ways to typical small 'spec' built housing available in the area. The overall cost of each unit had to be kept to a minimum due to the depressed nature of the house market in this particular area.

9.3 Component details

The first floor is to be precast concrete supplied by Bison from Leeds. It will contain 50mm diameter holes running the full length of the slab. The section is identical to that which was described and tested in Chap 8.

The ducting necessary to bring the air from the conservatory to the slab has been kept to a minimum. The ducts have been made as large as possible. The duct to the plenum is 200mm diameter, the plenum is 125mm x 325mm running the length of the concrete for 3.7m to the left and 2.3m to the right. There is a 90 entry bend of 50mm diameter to each hole and a similar bend at exit. The plenum at the outlet end is of 125mm x 325mm for 4.2m on the right hand side and 1000mm x 100mm on the left hand side.

The gas fired warm air heater is to be the type J15-22 MkIII by Johnson and Starley. It will be fitted with the 'Modairflow' system which varies the flow of warm air with heat requirement.

9.4 Air Flow

The fan incorporated with the warm air heater is intended to be the sole source of power for driving the air around the system. There is hence a need to estimate the pressure drop as air passes through the ducting and the concrete floor slab.

To facilitate this calculation, equations from Flow of Fluids in Pipes and Ducts (I.H.V.E.,1970) have been used, as have been the k factors of bends and openings etc. To enable greater freedom in the design a general equation in terms of air flow was developed.

Let:

Overall flow	Q_V m³/s
Area of unit	A m^2
Velocity	v m/s

$$Q_V = v\,A \quad \text{or} \quad v = Q_V / A \tag{9.1}$$

losses due to bends etc.:

$$\Delta P = (k \rho v^2) / 2 \tag{9.2}$$

Entry Duct

$k = 0.43 \quad \rho = 1.2\ kg/m^3$

$$v = Q_V / 0.031 \tag{9.3}$$

$$\Delta P = (0.43 \times 1.2 \times Q_V^2) / (2 \times 0.031^2) \tag{9.4}$$

Bend from duct to plenum

Due to enlargement:

$$v_2 / v_1 = A_1 / A_4 = 0.785 \quad \text{hence} \quad k = 0.11 \tag{9.5}$$

$$\Delta P = (0.11 \times 1.2 \times Q_V^2)/(2 \times 0.031^2) \tag{9.6}$$

Bend (x2)

$k = 1.25$

$$Q_{V1} = 3.7\,Q_V / 6 \qquad Q_{V2} = 2.3\,Q_V / 6 \tag{9.7}$$

$$\text{bend} = (1.25 \times 1.2 \times 0.61^2 \times Q_v^2) \,/\, (2 \times 0.44^2) \qquad (9.8)$$

$$\text{bend} = (1.25 \times 1.2 \times 0.38^2 \times Q_v^2) \,/\, (2 \times 0.04^2) \qquad (9.9)$$

sub total (9.8) + (9.9) $= 311\ Q_v^2$

Entrance to concrete

$Q_{v1} = Q_v / 40 \qquad A_1 = 1.96 \times 10^{-3} \quad k = 0.43$

$$\Delta P = (40 \times 0.43 \times 1.2 \times Q_v^2) \,/\, (2 \times 40^2 \times (1.96 \times 10^{-3})^2) \qquad (9.10)$$

sub total $= 1673\ Q_v^2$

Bend in concrete entrance (twice)

$Q_{v1} = Q_v / 40 \qquad A_1 = 1.96 \times 10^{-3}$

$$\Delta P = (2 \times 40 \times 1.25 \times 1.2 \times Q_v^2) \,/\, (2 \times 40^2 \times (1.96 \times 10^{-3})^2) \qquad (9.11)$$

sub total $= 9761\ Q_v^2$

Exit from concrete

$Q_{v1} / Q_{v3} \quad 1.0 \Rightarrow 2.0$

hence $k = 0.58 \Rightarrow 0.17$ i.e. 0.375

$$\Delta P = (40 \times 0.375 \times 1.2 \times Q_v^2) \,/\, (2 \times 40 \times (1.96 \times 10^{-3})^2) \qquad (9.12)$$

sub total $= 1464\ Q_v^2$

Bend from duct to plenum

As above for entrance $\quad 311\ Q_v^2$

Loss through pipe

$k = 0.25 \times 10^{-3} \quad d = 0.05$ m $\quad Re = 1800$

$$f = 16 / Re = 8.9 \times 10^{-3} \qquad (9.13)$$

$$\Delta P = 2 f L v^2 / d = 10 Q_v^2 \qquad (9.14)$$

TOTAL

$$14200 Q_v^2$$

Table 9.1 shows the pressure drop for various air changes per hour.

The fan can deliver air at a rate of 35 - 40 L/s and the manufacturers suggest that the maximum allowable head for the purpose of bringing in air is 12 Pa. Hence a rate of about 2/3 of an air change per hour or below would be acceptable. A new setting is to be incorporated into the Johnson and Starley warm air heater units for the purpose of ventilation only. This would be ideal for the purpose of bringing warm air from the conservatory for heating the slab. The suggested rate by the manufacturor is 25% power which would be about 1/4 ac/h. This level can be modified at the factory.

9.5 Fan Speed

9.5.1 Effect upon heat output

The speed of the fan governs the rate at which heat is removed from the conservatory since warm air will be removed to be partly replaced by cooler air from outside. Too fast a fan may result in too rapid cooling of the conservatory allowing the temperature to drop unacceptably, with the possibility of it not being warmed further due to lack of sunshine. Conversely, too slow a fan may result in the poor use of the conservatory with unacceptably high temperatures.

The most desirable fan speed is therefore governed by the likely weather. Given a short burst of strong sunshine resulting in a rapid temperature rise of the air in the conservatory, a similar short burst of fast speed fan to output as much of the heat as possible would be desirable. Should the solar input be poor, a low level of fan speed such that the conservatory temperature does not drop significantly would be suitable.

The computer model SUNSPACE (Chap 6) was run with the data for the Wakefield houses to model the effects of different fan speeds. Flow of 0.012 m^3/s, 0.024 m^3/s and 0.036 m^3/s equivalent to air change rates of 1/3, 2/3 and 1 ac/h were considered. The criterion taken was the number of hours that the conservatory air temperature would exceed 15.5^oC.

Although at higher fan speeds the air will be at a lower temperature, the volume of air will be greater. The criterium of 15.5 ^{o}C was selected since air brought in at this temperature or above would not need to be warmed by the heater. This does not mean that air below this temperature is not useful, it may still warm the slab during the day or contribute to the reduction in fuel demand of the heater by providing prewarmed air to the system. However the greater the number of hours that air may be brought in without having to be heated is an important consideration in the overall system design. The hours of midnight to 6.00 h were ignored since a total switch off is envisaged during this time. The results are shown in Table 9.2.

The most striking point is how little the change of air speed alters the number of hours of output. Increasing the volume flow by a factor of three reduces the possible output from 46% of all hours considered to 42%. This would suggest that the fan speed may be chosen on grounds other than solar output.

9.5.2 The Heat Transfer in the Concrete Ducts

The rate of heat transfer from the air to the concrete wall is dependent upon the surface area of the duct, the temperature difference and the local heat transfer coefficient. It may be expressed as:

$$Q = \bar{h}_c A \, dT \tag{9.15}$$

The heat transfer coefficient will depend upon the thermal conductivity of the fluid and the nature of the flow. The heat transfer coefficient may be calculated if the Nusselt number is known. The Nusselt number depends on the ratio of the convective heat transfer coefficient to the thermal conductivity of the fluid.

$$\overline{Nu} = \overline{h}_c D / k_f \qquad (9.16)$$

Hence if the Nusselt number is known the heat transfer coefficient may be calculated.

Wong (1977) suggests the following equation for laminar flow in tubes.

$$\overline{Nu} = 3.66 \qquad (9.17)$$

Although the calculated Reynolds numbers of between 1000 and 2500 suggest laminar flow this is not necessarily the case. Because of the awkward path that the air must follow it is possible that the air flow may be turbulent. Although this would not be expected for these levels of volume flows with diameters of 50mm they are included for comparison.

It is impossible to describe the flow and only through examination of the exact circumstances can it be said whether it is laminar or turbulent.

From O'Callaghan(1978,p26):

$$\overline{Nu} = 0.023\ Re^{0.8}\ Pr^{0.3} \qquad (9.18)$$

This is for fluids where $0.5<Pr<100$ so that it applies in the case of air where the Prandtl number is 0.7.

Table 9.3 summarises the heat transfer coefficients likely to be found from the three air flow rates. As expected, the coefficients increase with air speed. However, the lower the speed of the air, the higher the air temperature as it passes through the slab. Dividing the heat transfer coefficients by the air flow rate gives a value in units of J/m^5K, an indication of the heat input for a temperature difference. This value decreases with volume flow. This is marked for laminar flow but is still significant given turbulent flow. The reader is referred to the appendix for an explanation of this phenomena from first principles. Since the temperature differences are higher with lower air flow rates, the input to the slab will be greater.

A low air flow rate is desirable for the purposes of heat transfer under these circumstances. Hence a flow rate of between 0.012 m^3/s and 0.024 m^3/s is desirable.

9.6 Control System

A sophisticated control system could be developed which would monitor the house and conservatory temperatures, the condition of the slab and its surface temperature and control the fan and heating system accordingly.

Experimental work has shown that the concrete surface temperatures will not increase to unacceptable levels no matter what the heat input is. A complicated control system would need to be microprocessor controlled, its main advantage being that it could vary the speed of the fan according to the conditions. As shown above the fan speed is not that critical and it is felt that this is an unecessary cost to pay.

The simplest alternative would be to use the ventilation setting of the fan and to leave the fan on at a low setting whenever the house is unoccupied. This would result however, in cool air being blown into the slab occasionally, discharging it unnecessarily.

An adequate alternative for unoccupied periods is to measure the conservatory air temperature and the air temperature at the exit of the slab. If the former is greater, switch on. The output of the slab is unlikely to be lower than the general house temperature because the concrete floor will be at worst, at the overall house temperature. Should the conservatory have no contribution to make, the air will be warmed, resulting in an output temperature higher than that of the conservatory, hence switch off.

As the slab becomes charged, experimental work shows that the outlet temperature rises close to the inlet temperature. As soon as the conservatory temperature drops and the slab is well charged the fan will switch off, ensuring no discharge of the slab.

The differential thermostat will be connected in parallel to the main fan switch. During the day, the differential thermostat will control the fan and at times of occupancy the normal control will operate the fan.

Table 9.1 PRESSURE DROP

ac/h	Q m^3/s	Q cuft./min	P Pa
¼	8.4×10^{-3}	17.8	1.0
⅓	11.2×10^{-3}	23.7	1.8
½	16.8×10^{-3}	35.6	4.0
1	33.6×10^{-3}	71.2	16.0
1½	50.4×10^{-3}	106.8	36.1

ac/h : air changes per hour

Table 9.2 NUMBER AND PERCENTAGE OF HOURS WHEN THE CONSERVATORY TEMPERATURE EXCEEDS 15.5°C

	0.012 m^3/s		0.024 m^3/s		0.036 m^3/s	
Month	n	%	n	%	n	%
Jan.	0	0	0	0	0	0
Feb.	13	2	10	2	8	2
Mar.	128	22	112	19	98	17
Apr.	268	47	247	43	233	42
May	373	63	347	59	331	56
June	518	91	506	88	494	87
July	556	94	549	93	543	92
Aug.	532	90	520	88	517	88
Sep.	485	76	421	74	404	71
Oct.	253	43	231	39	219	31
Nov.	10	18	85	15	69	12
Dec.	2	0	1	0	0	0
Year	3179	46%	3029	44%	2916	42%

Kew Weather Data 1959-68

Table 9.3 Expected heat transfer coefficients

Flow	Re	Laminar		Turbulent	
		h_c	h_c/Q	h_c	h_c/Q
m^3/s		W/m^2K	J/m^5K	W/m^2K	J/m^5K
0.012	540	1.9	160	1.6	130
0.024	1100	1.9	80	2.9	120
0.036	1600	1.9	50	3.9	110

As the flow rate increases h_c/Q decreases. Since the temperature differences will be higher with lower flow rates, the lower rate is desirable.

CHAPTER 10 CONCLUSIONS

10.1 Emphasis

The intention of this work has been the detailed analysis of the constituent parts of a simple whole house passive solar heating system. The passive heating system was designed for new houses. One of the primary objectives has been that of cost. It was accepted that the total contribution the sun may make to the heating of a house may not be large, hence, it was important to keep costs low. Harnessing a large proportion of this energy could prove expensive.

It was accepted at the start of this research that there is an increased awareness of energy wastage in the home and many improvements have been made to both new and old housing that may reduce the total solar benefits. Throughout the development of the passive system, these problems have been borne in mind and used to the advantage of the whole house heating system.

10.2 Primary Conclusions

The result of this work is a simple passive solar system that incorporates components likely to be included in a new house: namely central heating and a first floor store. Additionally, a conservatory is included, the expense of which is justified on the grounds of desirability and increased living space. If the additional living space is heated by the occupants, this will detract from any saving.

Extra ductwork will be required as will a more sophisticated control system. The total additional cost is likely to be between £50 and £100 at 1986 prices.

The system's benefit will be a shortening of the heating season at the beginning and end of the heating season and a reduction in fuel costs throughout the rest of the year. Since the system works primarily by warming the air necessary for ventilation, its efficiency will not be reduced by the inclusion of other energy saving features such as double glazing. Hence, whenever the house is occupied and ventilation is necessary, the system will reduce the energy need. Ventilating air will be drawn, prewarmed by the conservatory, into the warm air heater rather than via natural infiltration. This is the usual case for warm air heated houses where ventilated air is drawn from outside directly to the heater.

The system may be viewed as a useful addition to new houses which will reduce the occupant's fuel bills in much the same way as cavity wall insulation.

The use of a concrete first floor slab's natural heat storage capacity as a heat store for warming the outside air at times of no sun is beneficial. Although the floor is not an efficient store, any heat losses will be to the fabric of the house and not to the outside.

A simple and cheap addition to new houses has been developed such that the sun is used to reduce the heating demand in North European climates without advanced technology and sophisticated design.

10.3 Specific conclusions

Along with the development of the whole house heating system, certain specific conclusions were arrived at.

- The importance of the orientation of buildings varies throughout the year. At the beginning and end of the heating season orientations are less critical for direct sunlight than at the middle of the heating season.

- Orientation is most significant for the time of maximum solar input.

- Most houses in the U.K. are underoccupied hence centrally heated houses use more fuel than locally heated houses since unused rooms are being heated. A system which provides cheap background heat will be useful enabling the occupant to "top up" the room where necessary.

- The fabric of the conservatory was always found to be warmer than the conservatory air which was in turn found to be warmer than the outside air.

- The conservatory's buffer component varied little with orientation or time of year.

- The conservatory delivery of warmed air varies from month to month and is affected somewhat by orientation.

- The ideal proportions for the conservatory are that the floor should take up rather more than half of the total surface area.

- The conservatory's efficiency overall as a provider of warmed air is about 15%. This is considering all air above 4 C to be useful since it can be warmed to comfort conditions by the warm air heating unit. Given intermittent occupancy this figure will be lower.

- The floor store is surrounded almost totally by the internal environment. It therefore makes a vary suitable store since its heat loss is to the house.

- A first floor slab has more than adequate storage potential.

- The main heat loss from the slab is by radiation but substantial amounts of heat are recoverable by blowing cool air through the slab.

10.3.1 Orientation of buildings

We receive large amounts of diffuse sunlight in the United Kingdom, overcast days are common. Because of this, orientation is less critical than in many climates due to the high proportion of non-directional energy.

Occupants who are in the house during the morning and evening only may well benefit from much glazing on the east or west to take advantage of direct gain at the time of greatest need rather than greatest supply.

Summing the total irradiance on opposing surfaces, for instance, east and west or north-east and south-west, housing laid on an east to west axis will receive the greatest direct gain.

10.3.2 Occupancy and domestic heating

The occcupancy and the time of occupancy are dependent largely upon the household size. In many large households there will be one or more family members at home during the day. Estimates (Section 4.2.3) suggest that this may be of the order of half to two-thirds of all households. Given this, there is a strong argument for simple direct solar heating that provides benefits to the occupants at the time of maximum solar input.

Although there is a trend towards the construction of smaller private houses much housing is underoccupied. This is true of both the council and private houses although it is much more prevalent in private houses. If the whole is heated then there is likely to be energy waste caused by heating unused rooms.

The nature of the occupancy, whether it is all day or morning and evening, does not affect room usage with the exception of the lounge. Room temperatures, particularly bedrooms, are higher in centrally heated houses than in locally heated houses. Rooms are also heated for longer periods in centrally heated houses than in locally heated ones.

Given these factors, fuel usage is likely to be higher in centrally than locally heated dwellings. Most occupants probably consider central heating desirable, so that any fuel saving measures should take this into account.

The system suggested in this work attempts to reduce fuel consumption whilst retaining comfort by providing a low level of free heat to all parts of the house. This is achieved by chanelling the solar gain directly to the central heating boiler and providing an even level of free radiated heat to all parts of the house. The system will behave differently with different users but should show benefit to all.

The price of fuel determines its use (Section 4.4.2). A rapid increase in the price of fuel will result in a reduction of consumption. Hence one possible way of extending the country's fuel reserves is to increase the price of fuel. This will not affect households similarly. The proportion of the household income that is spent on fuel is not constant. Households with low earnings spend proportionately more on fuel than others. Poor households are probably spending less on fuel than they would consider desirable to maintain adequate internal conditions. Any form of free energy for these households is likely to increase comfort rather than reduce consumption and expenditure. Hence systems that provide free energy will not necessarily show financial returns.

10.3.3 The conservatory

The conservatory model that was developed provided good predictions on the behaviour of a conservatory.

Orientation affects the total contribution of the conservatory. The greatest overall gain comes from conservatories that face south. For particular time intervals however, including those of zero solar input, improvements to the output can be made by altering the orientation. It is preferable to orient the conservatory to the west of south than to the east.

For a conservatory of height 2.8m, width 3.0m and depth 1.5m, the output varies from about 600 MJ/month in May for the warmed air component to about 150 MJ/month in December for a south facing conservatory. The corresponding values for the buffer component were 25 MJ/month and 40 MJ/month for November and February respetively.

From the figures in Table 7.1 an annual figure of about 3100 MJ gain for an occupied house with a conservatory of the type described in Chapter 6 corresponds to an annual saving of the order of £13 to £15 compared to providing the heat by gas.

Increasing the size of the conservatory but keeping the proportions the same improves the output. The overall collection per square metre of wall covered drops by about 20% in the middle of the heating season and by 25% at other times for a doubling of area covered.

For the purpose of buffer gain the area of floor covered is not important.

10.3.4 The floor slab

The efficiency of the slab is governed by the level of heat input. There is a minimum level of heat input requirred to ensure heat output. This is dependent upon the rate of heat input but is between 4MJ and 6MJ for the Wakefield houses.

The charging is not affected by stopping and starting of the heat input nor is the efficiency affected greatly by a long time before withdrawal of heat.

10.4 The heating system and controls

As was originally intended in this research, the main system of heating was to be gas fired warm air. It has been intended to keep the overall system as simple as possible, so that no major alterations are necessary to any of the components. This has generally been achieved.

There has been a need to develop a control system for the system. Once again this has been kept as simple as possible. The final solution has been to have a differential thermostat measuring temperatures at the inlet and the outlet of the slab. Provided the outlet temperature is lower that the inlet, the fan should be switched on for charging. When the house is occupied the fan and heater would be on when the temperature fell below comfort conditions.

The heater should be set such that "off" meant that the differential thermostat controlled the fan alone, whilst on meant that the room thermostat controlled the fan and the heater.

10.4.1 Improvements to the heating system

Although a fixed rate fan speed of 2/3 the normal value for charging has been selected, with the inclusion of Johnson and Starley's "Modair Flow", it would be possible to develop a control system that takes advantage of this. Should the temperature difference be large, the fan could run faster than otherwise.

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A more sophisticated monitoring system could be developed controlled by micro-processor measuring outside air temperature, conservatory air temperature, floor temperature and lounge air temperature and optimizing the use of the store and heater. As the price of the micro-processor drops further, this may become viable. It is probably not the case now.

10.5 Further work on the house system

A row of terraced houses including the solar system described are being built in Wakefield, West Yorkshire. They are due for completion in late 1986 and a programme of monitoring financed by the E.E.C. is proposed. From this, actual estimates of the energy saving will be made and the behaviour of the concrete slab and the conservatory can be examined.

The monitoring will be undertaken in occupied houses so there will not be the opportunity to have controlled conditions.

Different types of control systems will be examined.

10.6 Further detailed work on the conservatory

It is intended to monitor fully at least one of the Wakefield houses.

for both the air gain and buffer gain was found for this size of conservatory with full occupancy and all air over 4 ^{o}C being useful. Given a gas heated house with an efficiency of about 75% this represents a saving of between £14 and £15 per annum.

Increasing the size of the conservatory but keeping the proportions the same improves the output. The overall collection per square metre of wall covered drops by about 20% in the middle of the heating season and by 25% at other times for a doubling of area covered.

For the purposes of buffer gain, the area of floor covered is not important.

10.3.4 The floor slab

The efficiency of the slab is governed by the level of heat input. There is a minimum level of heat input required to ensure heat output. This is dependent upon the rate of heat input but is between 4MJ and 6MJ for the Wakefield houses.

The charging of the slab is affected little by stopping and starting of the heat input nor is the efficiency affected greatly by a long time before withdrawal of heat.

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For conservatories generally, an experiment with three or more conservatories of different sizes should be carried out.

Other areas of interest would be the use of synthetic and special glass, the use of double glazing and the effect of movable shutters covering the area of glass between the conservatory and the house. This would cut down the effect of direct gain to the house but should improve the contribution of warmed air gain.

10.7 Further detailed work on the concrete slab

One particular type of precast concrete floor was investigated. There is a large range of precast floor slabs on the market. Many of these are obviously unsuitable but an investigation into the performance of the others is worthwile. The design of a floor slab specifically for this purpose may be feasible.

The precise performance of the floor slab will be monitored during the Wakefield monitoring and this may indicate improvements to be made.

Of particular consideration are the size of hole for the airflow rate, and their number and spacing. The effect of the concrete mix should be investigated.

10.8 Application of the conservatory model

The conservatory model "SUNSPACE" is written in standard FORTRAN 77 and is machine independent. It requires suitable weather data in the standard meteorological format but the FORTRAN code can be changed easily to use different data.

The program may be run to simulate the behaviour of a conservatory over a period thus enabling the designer to estimate the value of the conservatory as a solar collector and buffer space. The designer can alter the data contained on the file SPACE to see how various conservatory options perform.

10.9 General discussion

The reserves of fossil fuel are slowly declining Exploration for oil continues and it is likely that more will be found ensuring the continued use of this fuel for several decades. The outlook for natural gas is similar. The United Kingdom is particularly fortunate with our reserves of coal which should last us several hundred years.

We are taking greater care of the fuel that we have available, the efficiency of most fuel users is increasing. The new generation of large coal fired generating stations such as Drax are much more efficient than the older types. The CEGB uses the highly efficient boilers at all times and only introduces the less efficient boilers to cope with the peak load.

The advantage that electricity has over the other forms of supplied energy to the consumer, is that the consumer need not be aware of which primary fuel is generating the power. It could be, most typically, a coal fired power station or alternatively nuclear or hydro-electricity for instance. As the availability of a particular fuel decreases, the generating body has to switch to another fuel. The consumers only note is the possible change in tariff, significant though that may be.

The ability to change from one fuel to another, with little effect on the consumer, was shown most successfully during the miner's strike of 1984-85. Some coal was produced and this was used in the most efficient local coal fired stations such as Radcliff on Soar. The less efficient coal fired stations were completely closed. The nuclear power stations were running at full capacity and many old and inefficient oil powered stations were brought into use. The massive drop in oil prices in early 1986 has made oil generating stations more viable.

Certain forms of power generation such as nuclear, hydro and waves are suitable only for central generation. Should these energy sources become the main means of power supply, it has to be done centrally.

Nuclear power poses many questions polarising the issue on whether power has to be generated centrally. It is perceived as a dangerous fuel by the public. Until recently it has been responsible for few fatalities but the Chernobyl disaster in the Soviet Union has shown that the potential for horrendous disaster is there. The Con-Edison nuclear generating plant in Long Island, New York has yet to be commissioned and looks unlikely ever to come on stream primarily because of local safety fears. Nuclear power has however proven to be a successful supplier of electricity. In France, for instance, over 50% of the generating power is nuclear.

In Britain we have to decide whether nuclear fuel is to be the major supplier of power. Given our supplies of coal this does not appear necessary. We could attempt to fill the shortfall in energy capacity by energy saving means rather than nuclear fuel.

The difficulty with certain forms of energy is the inability to switch them on and off. Hydro-electricity is generated at all times as is wave power and nuclear power. As these forms of energy play an increasing role, there is a need to even out the energy demand for electricity, or more particularly to create demand for it at times of little use. For this reason we have have off peak charges for electricity and a system of heating by electricity which makes use of this energy. This seems wasteful to create an artificial demand for power that would otherwise not be there even though it may somewhat reduce the demand at other times.

Centralising the means of energy production has certain advantages as shown above. The same may be true for heating, although it is generally done on a smaller scale. It is inherently more efficient since a primary fuel is being turned directly into heat rather than first into a secondary fuel and then heat. Again, the fuel can be changed in the future.

District heating has a good future as a means of reducing the country's fuel bill. The benefits are greater if the fuel is a by-product of another process such as at the district heating system in Nottingham where heat is generated for council estates from the refuse incinerator. Combined heat and power stations have a great advantage. The wasted heat generated at the power station may be harnassed for district heating. This is true also for commercial uses. Drax power station uses a small proportion of the excess heat to heat an enormous array of greenhouses where tomatoes are grown.

The selection of a particular fuel for heating is governed by availability and price. The consumer is likely to chose the cheapest means of heating. We have seen however that many people are not spending as much on fuel as they would like. All too often, these people are stuck with the most expensive form of heating, electricity at peak rate, and are unable to change. More efficient forms of heating may not result in fuel saving but an improvement in comfort. The improved efficiencies of power stations and the lower priced energy that they deliver at night are of little benefit to these people since they may not easily install the necessary appliances.

Where the houses are administered centrally, district heating should benefit all occupants financially and in improved comfort.

There is much that can be done locally. There has been an increased desire for energy saving, the Building Regulations giving new houses much more insulation. We are still behind other countries such as the Scandinavian countries.

It is locally rather than centrally that solar systems fit. Solar systems are not ideal for all houses but there are still a large proportion for which it is.

Solar systems have to overcome the public reticence and the notion that they should be total providers of heat or power. Brinkworth (1972) showed that the contribution of the sun is good in the U.K. The total insolation on the horizontal is 1700 kWh/m in the U.K. for clear conditions, the nett insolation being about 60% of this. This compares favourably with 2300 kWh/m in the tropics. There is potential for saving energy by using the sun's energy. Brinkworth, however, also showed that there is a large variation in intensity through the year at lattitudes similar to that of the United Kingdom. The greatest insolation being in June and the lowest in December. Solar systems are therefore most useful as a means of reducing the length of the heating season at the beginning and end of the heating season. At other times they are efficient energy savers supplementing other heating systems.

In the future houses may be built with a view to maximising the power of the sun. Providing that solar systems can show themselves to be economic, there should be no objection to their implementation into housing.

It is essential that solar systems should be adequately marketed so that they can fit into a coordinated future energy policy along with district heating, combined heat and power and generally more efficient means of energy production.

We should strive to make energy management and fuel conservation as important as the search for new fuel sources, and invest money where its return is greatest.

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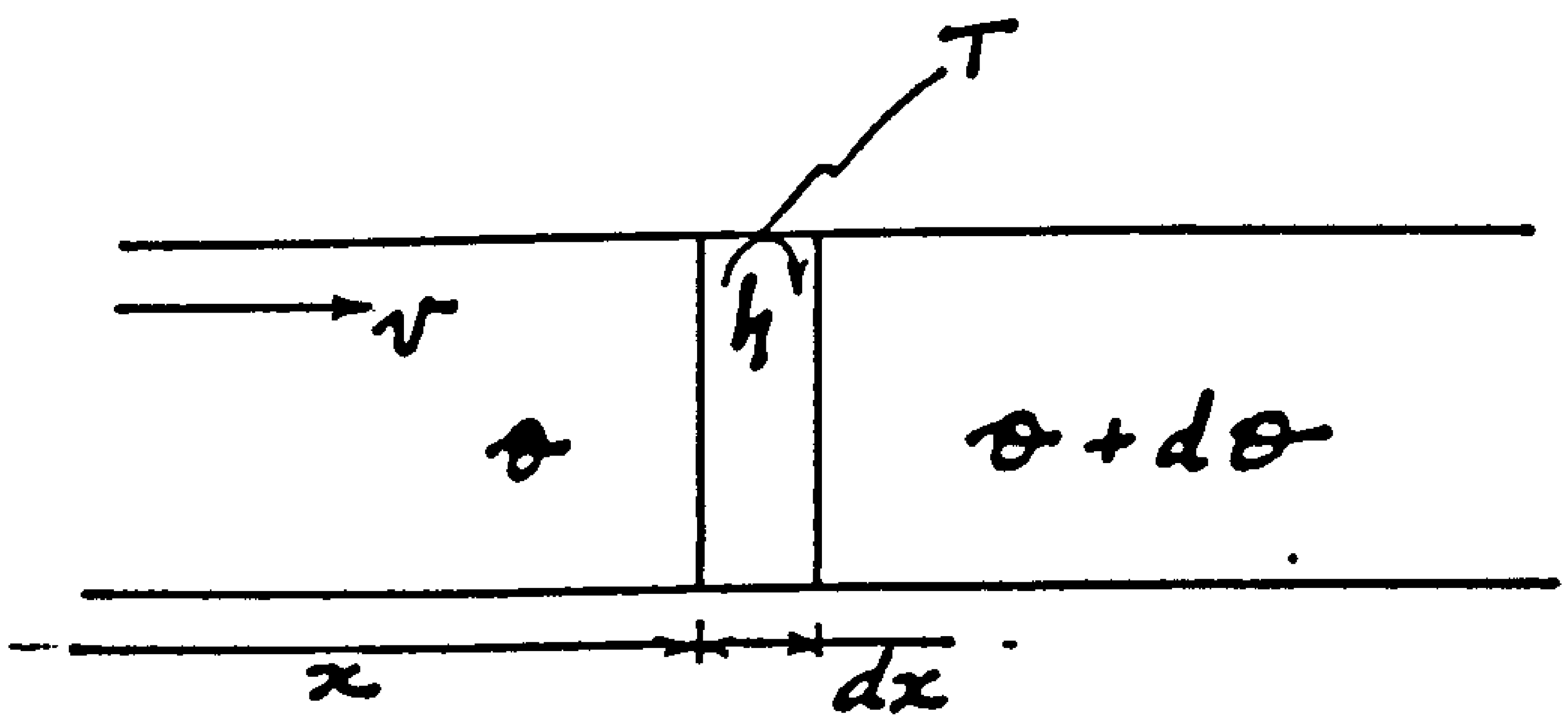
APPENDIX

To analyse the decrease in efficiency with increased velocities, consider air flow through a circular pipe of diameter D. The heat flow is as shown below:



Heat balance on a slice of thickness dx:

$$\rho v \frac{\pi D^2}{4} c \; d\theta = (T-\theta) h \pi D \, dx \qquad \text{(A.1)}$$

hence:

$$\frac{d\theta}{T-\theta} = \frac{4h\,dx}{\rho v D c} \qquad \text{(A.2)}$$

$$-\ln (T-\theta) = \frac{4hx}{\rho v D c} + \text{constant} \qquad \text{(A.3)}$$

when x=0 $\quad \theta = \theta_0 \quad \therefore$ const.= $-\ln (T-\theta_0)$

(A.3) becomes:

$$\frac{T-\theta}{T-\theta_0} = \exp\left(\frac{-4hx}{\rho v D c}\right) \tag{A.4}$$

For laminar flow, using equation (9.17) for D= 0.05m

$$\frac{4hx}{\rho v D c} = 0.133\,\frac{x}{v} \tag{A.5}$$

For turbulent flow, using equation (9.18) for D= 0.05m

$$\frac{4hx}{\rho v D c} = 0.382\,\frac{x}{v^{0.2}} \tag{A.6}$$

Mass flow: $\rho v \frac{\pi D^2}{4}$ kg/s (A.7)

Energy flow at 0°C: $\rho v \frac{\pi D^2}{4} c\,\theta$ W (A.8)

Rate of increase: $\rho v \frac{\pi D^2}{4} c\,\frac{d\theta}{dx}$ (A.9)

from (A.4) and (A.9)

$$\frac{d\theta}{dx} = \frac{4(T-\theta)h}{\rho v D c} = \frac{4h}{\rho v D c}(T-\theta_0)\exp\left(\frac{-4hx}{\rho v D c}\right) \tag{A.10}$$