UNIVERSITY OF NEWCASTLE UPON TYNE

DEPARTMENT OF MINING ENGINEERING

COMPUTER MODELLING OF TRANSIENT HEAT FLOW IN MINES

By

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ABSTRACT

The traditional method to predict air temperatures in mine roadways is based on the assumption that the ventilation air temperature remains constant over the ventilated age of the roadway. Hence, a steady-state solution prevails. As the capital investment of providing an acceptable working environment in hot and deep mines is increasing, more accurate and reliable temperature predictions in mine roadways will be needed in future mine ventilation planning. For this reason, a transient model to predict weekly air temperatures in mine roadways is developed.

The transient model is presented in the form of a computer program. It is constructed from the mathematical techniques developed for calculating the transient heat flow from strata (Cheung, 1988), conveyed coal (Cheung and Rabia, 1989) and structural steel (Maneylaws, 1988), and the empirical equations developed by Browning et al (1981) for estimating the heat from machinery. Duhamel's Theorem is used in the mathematical technique for calculating the transient heat flow from strata and conveyed coal. Details of these techniques are derived. In addition, the algorithm of the computer program is presented in terms of flow charts.

Climatic investigations were undertaken at British Coal Collieries; three sites at Wearmouth Colliery, Sunderland, and one site at Whitemoor Colliery, Selby. During the investigations, temperature surveys were conducted at all the sites. Using the data collected from these sites, the transient model is validated against field measurements and agreeable correlation achieved. Moreover, recommendations are made to improve the model.

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CHAPTER ONE

INTRODUCTION

Deeper working, together with increased mechanisation and an increase in machine power, has caused severe problems in mine climate, which result in a steady increase in the air temperature at the working face. There are four reasons for this:

(1) Increased strata temperature due to deeper working which will inevitably increase the rate of heat flow from strata,

(2) Increased heat transfer from cut coal because of higher output,

(3) Increased heat emitted from machinery due to an increase in the use of high-powered machinery,

and (4) Deterioration of air condition as it arrives at the working face due to the long ventilation circuits serving districts remote from the shaft.

During the seventies, extensive investigations into mine climate were undertaken by the Mine Research and Development Establishment (MRDE) (Browning et al, 1977; Whittaker, 1979; Browning, 1980; Browning and Burrell, 1980). These investigations concluded that the major heat sources were those described in (1) to (3) above, for which emission rates varied with time. In addition, comparison between the heat emission rates from the major heat sources, and the heat pick-ups by the ventilation air, at various times during a week, revealed a heat 'storage' mechanism taking place during the period of peak production.

In planning and controlling ventilation in mines, it is always of interest, and often essential, to be able to predict, with accuracy, the climatic conditions likely to occur in underground workings. This is critical where a working environment is concerned. For this, it is necessary to model transient temperatures.

The objectives of this project are as follows:

(1) To study and develop theoretical techniques, which can be used to calculate the transient heat flow from strata and conveyed coal, from machinery and from heat storage in structural steel.

(2) To develop a transient model, incorporating the mathematical techniques developed in (1), for predicting weekly air temperatures in underground roadways; e.g. conveyor roadways, maingates and tailgates.

(3) To undertake climatic surveys at four sites in two collieries, Wearmouth colliery, Sunderland, England, and Whitemoor Colliery, Selby, England, and to collect in-situ measurements of the temperature and humidity of the ventilation air at these sites.

(4) To produce temperature predictions from the transient model of (2) and the steady-state model developed by Maughan (1988), and make comparisons between the predicted temperatures obtained from both models and actual temperatures.

In achieving these objectives, the project is divided into two parts; one theoretical and the other experimental.

The theoretical work consists of developing mathematical models and software for estimating the heat flux from the major heat sources in mines. The mathematical models for calculating the heat flows from strata and conveyed coal are similar to each other, in that the Duhamel Theorem (Carslaw and Jaeger, 1959) is used to describe the heat conduction processes occurring in the strata and conveyed coal. The heat from machinery is difficult to model mathematically, and hence, the semi-empirical equations developed by Browning et al (1982) are used. The effect of heat storage in structural steel is based on the Lumped Capacity Method. The resulting computer program is able to calculate the heat flux from the major heat sources in a roadway and then the temperature rise along the roadway.

The experimental work was undertaken at three sites in Wearmouth Colliery and at a site in Whitemoor Colliery. These sites included an intake roadway, a conveyor roadway, and districts with an advance and a retreat production face. Thermohygrographs were installed at these sites to record air temperatures and humidity continuously over a period of two weeks. In addition, the area of the roadway and the air velocity were measured. The data obtained from the sites were then processed at British Coal HQTD, Bretby, England, where the operating hours of the conveyor in Whitemoor was also obtained from the Colliery Information System. This system is currently used to record information about mining operations in modern collieries. Information can be retrieved from a computer terminal either at the colliery or at HQTD. Other input data required by the programme were provided by the ventilation engineers at both collieries.

CHAPTER TWO

STUDY OF MINE CLIMATE

A poor mine environment, due to hot and humid conditions, usually occurs in deep mines with high strata temperatures, and in working districts remote from the shaft. Since mine workings in some British mines have reached a depth exceeding 1000m, the provision of reasonable working conditions has become very important to the health and safety of the mineworker. The main effects on mineworkers in districts with high effective temperatures, are loss of interest in the job and inattention to normal safe practices.

In order to provide an acceptable working environment, cooling equipment is installed at districts with high effective temperatures. An alternative method for districts which are remote from the shaft and which have moderate strata temperature, is to increase the ventilation quantity (i.e. volume of air) either by installing larger booster fans or introducing a system to recirculate mine air. Both of these techniques require large capital investment. For this reason, when planning mine ventilation for a new development, it is necessary to predict where and when, and in what quantity , heat is emitted into the district, and how this heat can be removed in order to maintain acceptable working conditions.

The advent of computer technology has led to the development of much computer software to assist in mine ventilation planning and in controlling the climatic condition in mines. This software provides predictions, of ventilation quantity using network analysis, of methane emission, of dust concentration and of ventilation air temperature. Only that software used in the prediction of air temperature will be discussed.

2.1 INVESTIGATION OF MINE CLIMATE

In 1955, Oakes and Hinsley (1955,a,b,c) began their studies on the heat exchanges occurring in a whole mine. They listed, and measured the magnitude of, a large number of heat sources. These heat sources are as follows:

(1) heat from strata,

(2) heat from electrical plant,

(3) heat from auto-compression in the downcast shaft and dip workings,

(4) heat from diesel locomotives,

(5) heat from men,

(6) heat from lamps,

and (7) heat from oxidation of carbonaceous materials.

They concluded that the heat from the strata accounted for 70 - 80 % of the heat emitted in a mine. The heat from electrical plant, operated during the working shifts, had a significant effect on the air temperature as well as on the rate of heat flow from strata. The heat from auto-compression is of great importance only at great depths. The heat contributions from the other heat sources, except the heat from oxidation, are relatively small. They have little effect on raising the air temperature. They suggested that the heat from oxidation was difficult to quantify, and the heat given out by this source could be balanced by methane desorption, which is a chemical reaction occurring in mines causing heat to be absorbed.

Roberts (1960) also listed heat sources similar to those described by Oakes and Hinsley (1955, a, b, c). He extended the discussion of mine climate to include a consideration of air-conditioning in mines.

Different mine climatic surveys were undertaken by Sharp (1967). He investigated the moisture in deep mines because at high air temperatures the humidity of the air becomes very important in determining whether or not a given climate is acceptable as a working environment. From observing the measurements taken at three collieries, he pointed out that there would be a large increase in moisture content whenever mining operations were taking place. The amount of moisture emitted from strata surface was negligible compared with the moisture pick-up from free water sources. He thus concluded that the moisture on the strata surface should be regarded as a minor source of moisture, and the free water surface caused by the service water (water used for dust suppression and cooling) is the major source of moisture, in mines.

2.1.1 Longwall Mining Districts In Britain

Extensive investigations into mine climate started again during the seventies when there was renewed interest in the control of heat and humidity in European mines. This was because the modernisation of mining techniques caused an increase in the use of more high-powered machinery to achieve higher coal output. There was also an expectancy on the part of mineworkers for improved working conditions.

Environmental conditions for mineworkers in underground mines have been discussed in the literature, most recently by Whillier (1982).

The study of mine climate was reviewed by Jones (1972) who considered heat flow in mine roadways. He outlined a simplified method for measuring thermal conductivity, and calculating the surface temperature of the strata, in a roadway. The effects caused by evaporation of moisture and mechanisation at the heading and face and the effect on the effective temperature limits in working mines, were discussed.

Since most mineworkers encounter heat and humidity in longwall districts, most of the research is directed to these areas.

Gracie and Matthew (1975) investigated the heat flow in a longwall district at Florence Colliery, England. From their investigations at this site, they pointed out the importance of an extra heat source, the conveyed coal, in the gateroad and the face. An elementary calculation of the heat from conveyed coal by Gracie and Matthew (1975) showed that coal production at a rate of 4 tonnes/minute, with a temperature drop of 10 °C through a conveyor roadway, could release heat energy of 737 kW into the roadway. In addition, they made in-situ measurements on conveyed coal by placing a thermometer in a bucketful of coal obtained from the conveyor at the site. They showed that the coal on the conveyor, with a temperature drop of 10 °C through the conveyor roadway, could emit heat of 600 kW, with the conveyor machinery contributing about 170 kW. However, the measuring technique was not very convincing (Whittaker, 1975) as the temperature so recorded is that of the fine coal immediately surrounding the thermometer bulb, and takes no account of the temperature of the lump coal which loses heat more slowly than the fines. Therefore, the measurements made by Gracie and Matthew (1975) might over estimated the heat emitted by conveyed coal.

The effect of heat storage in structural steel was also discussed by Gracie and Matthew (1975). They suggested that a large quantity of steelwork in the gateroad and the face could have a substantial influence on air temperature. The steelwork could store heat from the ventilation air when there was an increase in the air temperature, which could then be released when air temperature decreased.

In 1977, the climate in British mines was considered by MRDE (Browning et al, 1977). Detailed investigations were made at four longwall districts (coalface and maingate) covering a range of strata temperatures and operating conditions. Less detailed measurements were also made at two additional longwall districts. The trunk conveyor systems serving two of the four districts were also investigated in detail. Browning et al (1977) reported that the major heat sources in a longwall district are the strata, the cut coal (inclusive of conveyed coal) and the machinery. They undertook measurements to quantify the heat emitted by these heat sources and the heat picked-up by the ventilation air at those sites. Temperature measurements were made on the cut coal, the water used for the cutting process and the ventilation air. Electrical power measurements were made on the electrical machinery operating in the district. Since no direct measurements could be made of the heat flow from strata, the StBV program developed by Voss (1969) was used to compute the heat from the strata. This program is currently used by British Coal, U.K. for climate predictions. The data which are required by the program, equivalent thermal conductivity and the wetness factor of the gateroad and the face were measured during the weekend when production ceased. This was because the heat from the strata is the only heat source at that time. From these measurements, Browning et al (1977) showed that a large proportion of the heat emissions was picked-up by evaporation of moisture (latent heat of evaporation). In addition, comparison between the heat emissions and the corresponding heat pick-up during the peak production period revealed a heat 'storage' mechanism. This is displayed in Figure 2.1 (c), which shows that the total heat emissions in the district have not been picked-up completely by the ventilation air. In order to ensure that accurate measurements were made during the investigations, heat balances over a week, using the same measurements of the heat emitted by the individual heat sources and the heat pick-up by the ventilation air were made, and satisfactory results were obtained as shown in Figure 2.1, (a).

Mine climate work was discussed by Whittaker (1979), who described a theoretical technique for predicting methane emissions, and investigating heat and humidity, in longwall districts. Whittaker (1980) further discussed mine climate work. He emphasised the importance of using good technique to measure the temperature of the conveyed coal, and the importance of heat from oxidation and that lost in methane absorption.

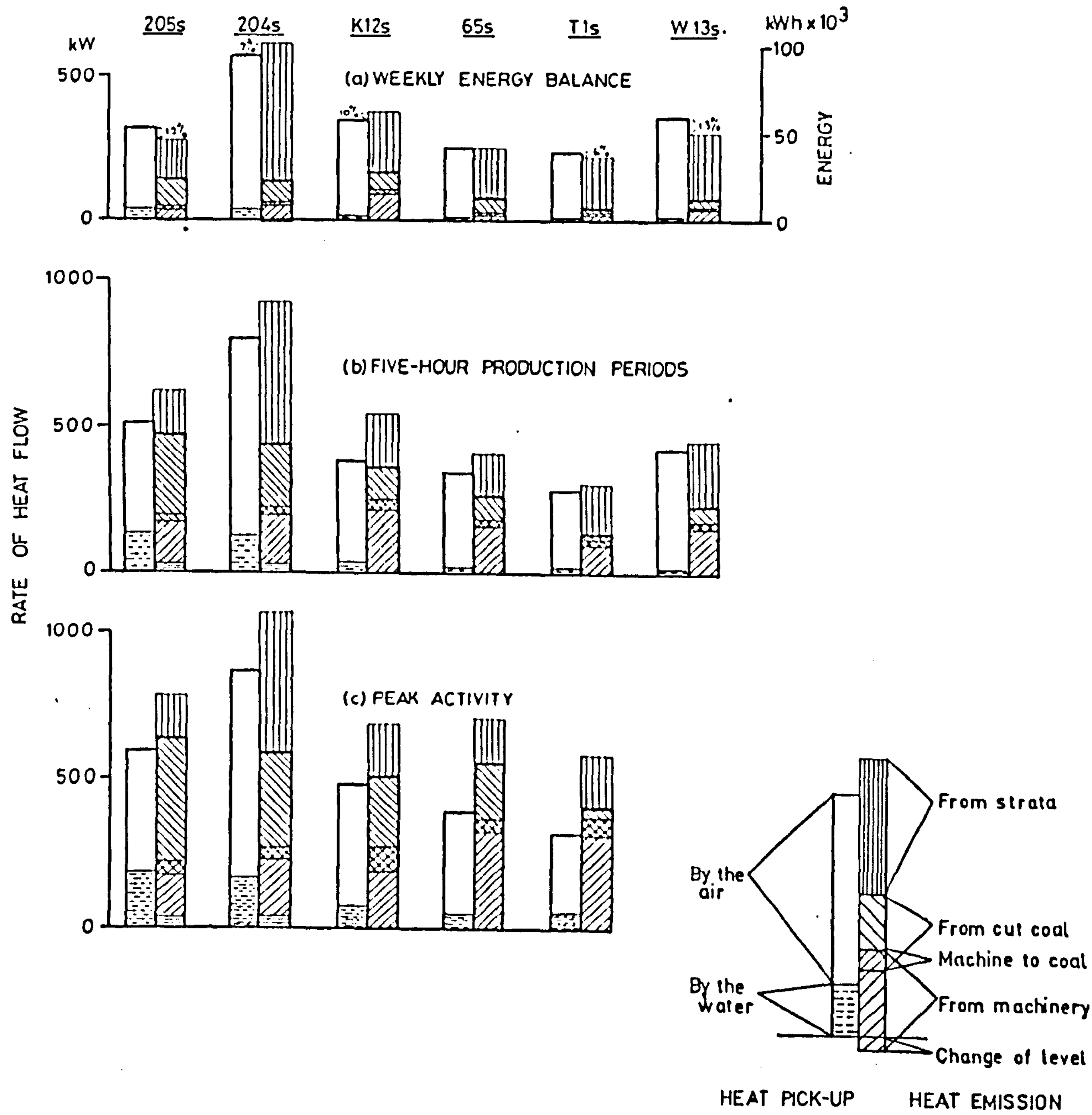


Figure 2.1 Energy Balances for the Six Longwall Districts (Browning et al, 1977)

Browning (1980) extended the discussion of the mine climate investigations undertaken by Browning et al (1977) to include the heat flow from the goaf (i.e. the waste behind the face). In addition, semi-empirical equations were developed for predicting the heat emitted by machinery operating in the gateroad and the face. Since the mining operation in the gateroad, where coal is conveyed outbye, is different from that in the face, where coal production is in process, Browning (1980) recommended that the study of heat flow in the gateroad should be separated from that of the face in the mining district.

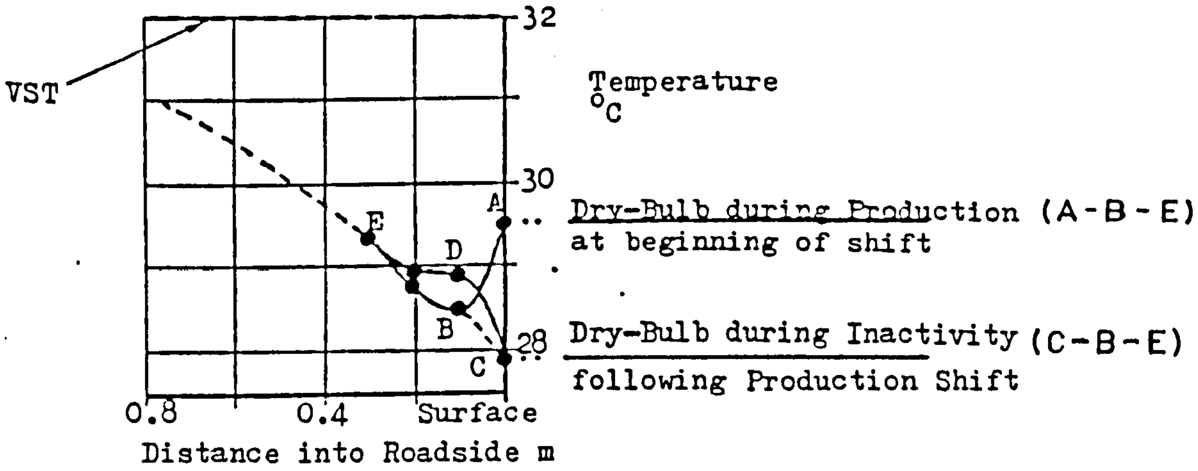


Figure 2.2 Strata Temperatures for Active and Inactive Periods (Browning and Burrell, 1980)

Browning and Burrell (1980) drew similar conclusions to those of Browning et al (1977) and Browning (1980). In addition, particular attention was paid to the transient heat flow from the strata. They conducted measurements in a borehole to illustrate the heat 'storage' mechanism in the strata. The measured temperatures are displayed in Figure 2.2, which shows that the temperature profile in the first 30 cm of the roadway wall changes with respect to the increase in temperature during production shift and the decrease in temperature during inactivity. The temperature gradient (D to C) shown in Figure 2.2 is negative where heat flows from strata to the ventilation air. When this heat flow is reversed, the temperature gradient becomes positive (A to B).

2.1.2 Longwall Mining Districts In Germany

Mine climate surveys were undertaken by the Mine Ventilation and Climate Technology Research Department (FGK), Bergbau-Forschung GmbH, Essen, Germany (Schlotte, 1980). The temperatures and humidities obtained from these surveys showed that variations of the dry bulb temperature and humidity were similar to those measured in British coalmines. In addition, Schlotte (1980) noted that the empirical equation developed for predicting the heat emitted from machinery at FGK in 1976, was no longer applicable to modern mining because the use of high powered machinery had increased since 1976. For this reason, a new empirical equation was developed by Schlotte (1980). He also emphasised the importance of the heat and moisture emissions from conveyed coal by using the measurements of the heat emissions and the heat pick-up in a district, which were obtained during the surveys, to develop a simple heat balance equation. This gives,

$$Q_w - Q_{G+A} - Q_E = Q_R \quad \text{(kW)} \tag{2.1}$$

$$1100 - 555 - 720 = -175 \quad \text{(kW)}$$

where Q_w = heat picked up by air (kW)

Q_{G+A} = heat flow from strata and goaf (kW)

Q_E = heat emitted by electrical equipment (kW)

Q_R = residual heat (kW)

If the residual heat is negative, heat is assumed to be gained by the conveyed coal. A positive residual heat means that heat is released by the conveyed coal.

Since 1986, Voss and Schnitters (1987) have carried out climate surveys on 207 faces in German coalmines. The surprising results were that, although, since 1978, the coal output had increased from 1304 to 1468 t/d, and an increase of the installed electrical power in workings from 1283 to 1672 kW had taken place, the climate in these coalmines had not worsened. This was due to the fact that there had been a great increase in the amount of cooling equipment installed at the workings. The total refrigeration capacity in German coalmines for air conditioning went up from 97MW in 1978 to about 290MW in 1986. This shows a considerable increase in the use of machinery and cooling equipment over a period of eight years. For this reason, Voss and Schnitters (1987) recommended that one climate survey be conducted once in every eight years.

2.2 DEVELOPMENT OF MINE CLIMATE PREDICTIONS

The main conclusion which may be drawn from mine climate investigations is that further deterioration of the mine climate in working districts will take place as the working seams go deeper into hotter strata, and that the capital investment for improving the working environment will increase. Therefore, there will be an increase in the demand for computer software to assist in mine ventilation planning in order to provide more accurate and reliable predictions of air temperature in mines.

The research establishments, Chamber of Mines in South Africa, Mine Ventilation and Research Technology Centre (FGK) in West Germany, Mining Research and Development Establishment (MRDE) in U.K. (This establishment is now known as British Coal Headquarter Technical Department, HQTD) and Department of Mining Engineering in Nottingham University, U.K., have all been engaged on the development of mine climate predictions programme. Some of their approaches to this work are similar to each other while some techniques developed by individual establishments will only be applicable to mining environments in their own countries.

2.2.1 The South African Approach

The theoretical solutions for heat flow from strata in a mine roadway were first given by Goch and Patterson (1940). They assumed that the roadway is an internally bounded circular cylinder, and infinite heat transfer occurs at the roadway surface (that is the surface temperature of the roadway strata is at the same temperature as the air temperature).

The heat conduction process in strata can be described by the Heat Diffusion Equation with appropriate initial and boundary conditions for the physical problem. The Heat Diffusion Equation given in a vector form is,

$$\nabla^2 T = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{2.2}$$

By solving equation (1.2) when subjected to an initial condition, $T = T_R$ at $t = 0$, and boundary condition, $T_s = T_a$ for $t > 0.$, and by making the assumptions outlined above, Goch and Patterson (1940) produced a mathematical table for finding the dimension-less temperature gradient at the roadway surface. This table enables the heat flux from the strata to be found.

Wiles (1954) developed a method to forecast the dry bulb and wet bulb temperature gradients based on manual calculations. Simple assumptions had to be made, and many constants were inevitably produced, in the theory, which would require investigation.

It was not until 1966 that computation methods to calculate the heat flow from stopes (Starfield, 1966a) and airways (Starfield, 1966b) were developed. Both methods assume that the stopes and airways are rectangular openings and that the heat flow from strata only takes place perpendicular to the roadway wall. In the calculation of strata heat flow in a roadway, the footwall of the roadway is assumed to be partially wetted. The degree of wetness is described by a wetness factor. The other walls of the roadway are assumed to be completely dry. The theory used to calculate the heat from strata in the roadway was originally developed by Jordan (1961). Since Jordan's technique was developed for the calculation of transient heat flow from strata, it allowed Starfield to show the effects of varying air temperature on the predicted temperature, and to calculate the temperature rise along the roadway.

At the same time, Starfield (1966b) produced a different mathematical table from that table derived by Goch and Patterson (1940). The difference between these two tables is that the solution of the Heat Diffusion Equation by Starfield (1966b) is based on a different boundary condition, convective heat transfer at the surface of a roadway, to that used by Goch and Patterson (1940).

An empirical approach was used to predict the wet bulb temperature gradients in mine airways by Lambrechts (1967). This technique is subject to large error limits because the measurements made in existing mine airways have large variations, and hence, the interpolation error of the data will be large. In addition, Lambrechts' assumption, which states that the dry bulb temperature has little significance in predicting air temperatures, is called into question. According to Whillier (1967), the assumption only applies to advancing stopes but not to mine roadways.

Whillier (1967) later demonstrated how heat equations could be used to calculate the sensible heat ("dry" heat), the latent heat and the effect of radiation, in mine airways.

The work by Starfield and Dickson (1967) was an improvement on Starfield's previous work (1966, b,c), in that they developed a computation method to calculate the strata heat flow in mines. The new method calculates the heat flow from strata using a finite difference method (Peaceman and Rachford, 1955) to solve the heat conduction equation, subject to certain assumptions being made, including the initial and boundary conditions, for the roadway. It is assumed in this method that, (i), the cross section of the roadway is a rectangular opening surrounded by homogeneous rock, (ii), the initial temperature of the rock is taken to be the virgin strata temperature, and (iii), rock temperature gradients parallel to the axis of the airway are ignored. In order to calculate the heat flux from strata, the heat transfer coefficient given by Rohsenhow and Choi (1963) is substituted into equation (2.3) so that the heat flux, F, through a partially wetted surface can be calculated according to equation (2.3) (Starfield and Dickson, 1967).

$$F = h \cdot (T_s - T_D) + fLE \cdot + H_{rad}(T_s - \overline{T}) \tag{2.3}$$

where
- h = the heat transfer coefficient (W/m²)
- T_s = the surface temperature (°C)
- T_D = the dry bulb temperature of air (°C)
- f = the wetness factor
- L = the latent heat of evaportaion (J/kg K)
- E = the mass transfer coefficient (m/s)
- H_{rad} = the radiation heat coefficient (W/m² K)
- $\overline{T}$ = the mean temperature of air (°C)

Once the heat flux from the strata is known, the temperature gradients of the airway can be calculated. Similar calculations were made with different virgin strata temperatures and with different wetness factors, and the results of these calculations were plotted in graphs showing temperature gradients verses the virgin strata temperatures for different wetness factors. The wetness factors were 0.0, 0.2 and 1.0. Wetness factors of 0.0 and 1.0 are extreme values. The first describes the footwall when completely dry and the other when completely wetted. A wetness factor of 0.2 is generally used for most partially wetted airways. Starfield and Dickson (1967) claimed good agreement between their predictions and those produced by Lambrechts (1967). They also suggested that closer agreement would be achieved if the method took account of the heat and moisture pick-up from pipes and drains in the airways.

Starfield (1969) developed a computer model using the method developed by Starfield and Dickson (1967) for predicting temperature gradients in mine airways. The use of this computer model requires the experience of a ventilation engineer because a practical judgement of the constants (e.g. wetness factor and the thermal properties of the strata) which are required by the programme, is needed. Neverthe-less, this model proved to be an useful tool for mine ventilation planning.

Renewed interests in heat and humidity in mines during the seventies allowed Vost (1982) to compare the computer models developed by Starfield (1969), and Gibson (1976). From these comparisons, Vost (1982) found that the heat transfer coefficient produced by the model developed by Gibson (1976), is greater than the one produced by Starfield's model. Furthermore, he compared the heat transfer coefficient obtained from his in-situ measurements with those obtained from both models, and better agreements were achieved with the values from the Starfield model. In addition, the comparison between the predicted temperatures obtained from both models, showed reasonable agreement between the predicted temperature and the actual temperature, especially for those predictions made at high virgin strata temperatures. The models developed by Starfield (1969), and Gibson (1976) were considered as being steady-state models, in which, varying air temperature history was not taken into account. Therefore, the predictions made by both models are only valid for predictions made when stable inlet temperatures exist for several days.

Although computation methods provide quick solutions for the heat flow in mine roadways, practical engineers may still prefer to use simplified methods to validate their computed results. Hemp (1985) reviewed some of the theory, and showed how manual calculations could be carried out, to provide approximate solutions for the temperature increase in roadways.

Van der Walt (1987) also developed a simplified method for calculating the heat from the strata and the heat from auxiliary equipment. Van der Walt (1987) knew this method to be inaccurate. Nevertheless, he thought it provided approximate solutions which were sufficiently accurate for the design of ventilation equipment.

2.2.2 The German Approach

The climate in German coalmines has been studied by the Ventilation and Climate Technology Department (FGK) in Germany. Most of the study related to the heat and humidity in mines has been undertaken by Voss.

Voss (1965) developed a mathematical technique to determine the heat and water vapour emissions from conveyed coal and dirt packs in gateroads and faces. The technique developed for the calculation of the heat from conveyed coal is based on the graphical method due to Schmidt (Cornwell, 1981). This method assumes that the conveyed coal on a continuous conveyor is in the form of a continuous slab. The limitation in using this method is that it does not take account of any mass transfer at the coal surface (water vapour emission). For this reason, the calculation had to begin at the underside of the conveyor. To verify the theoretical method, Voss carried out experiments to study the heat flow from conveyed coal in mines, and the results from these experiments were compared with the theoretical calculations of the heat from conveyed coal. These comparisons showed that the actual heat emission from the conveyed coal in the mine was found to be considerably higher than theoretical predictions because the thermal conductivity of the conveyed coal in a conveyor roadway has a higher value than those provided by the conventional laboratory experiments. The reason for the higher thermal conductivity value for the conveyed coal is due to the water sprayed on the coal, which increases the moisture content of the coal, for dust suppression. In order to obtain the thermal conductivity of conveyed coal from a laboratory experiment, Voss devised an experimental rig to produce similar thermal conductivity values to those obtained from in-situ measurements. In addition, Voss (1965) produced a worked example to illustrate how the theoretical method can be applied to the calculation of heat and moisture transfer from conveyed coal. In this example, the surface wetness of the coal is described by a wetness factor, and the rate of moisture transfer is proportional to the pressure difference between the saturation pressure at the surface temperature and the vapour pressure in the air. The constant of proportionality is the mass transfer coefficient. This coefficient obeys Lewis' Law.

Voss (1967) extended his mine climate calculation to include the heat flow from strata. He began to investigate the heat transfer coefficient, the thermal conductivity and the mass transfer coefficient, of the strata in mine airways. This was done by installing thermocouples at several sites in boreholes up to 14 m deep into the roadway strata. From the measurements of the strata temperature in the boreholes, the in-situ values for the thermal properties were calculated. The thermal properties found were then compared to the theoretical correlations for turbulent heat transfer in a cylinder. From these comparisons, it was concluded that the effective heat transfer coefficients for a wet roadway were higher than the theoretical values. The theoretical values was found to apply to a dry surface only.

The thermal parameters of the strata are important in the calculation of the heat flux from strata in a mine roadway. A theory to calculate the heat flux from the strata was then developed by Voss (1967) after the thermal parameters of the strata were established. However, the heat flux from the strata is not the only source of heat contributing to the increase of the air temperature at the end of the roadway. It is thus necessary to have methods to determine the heat flux from other heat sources if the temperature at the end of the roadway is required. Voss (1967) considered that the heat flux from other heat sources was equivalent to the heat flux from a thickness of strata in the roadway. This means that the heat emitted from the other heat sources is assumed to flow through an imaginary thickness of strata. Thus the theory developed to calculate the heat flux from the strata can be used to determine the heat flux from the other heat sources. Since all the heat flux flowing into the roadway is assumed to come from the strata, an equivalent thermal conductivity has to be used instead of the thermal conductivity of the strata, which is only used for calculating the heat flux from the strata. Hence, the theory developed to determine the heat flow from the strata can also be used to calculate the heat emitted by other heat sources in a roadway. In addition, Voss (1967) noted that the surface of roadways in underground mines is rarely free from moisture and water. From that, Voss described the roadway wetness by a wetness factor, and undertook experiments to determine the degree of wetness of mine roadways. A wetness factor of 0.3 is for an extremely wet roadway, and values between 0.02 to 0.14 apply for most partially wetted roadways.

Two computer models were developed by Voss (1969) to predict the temperature increase in a mine roadway (Model A and Model B). Model A is a two surface model, in that one surface is completely dry and the other is partially wetted. Model B is a single surface model, in that moisture is considered to be equally distributed over the roadway surface. The surface temperature of the roadway strata is first calculated as shown in equation (2.4), and the "dry" and latent heat flux from the strata can then be calculated according to equation (2.5) and (2.6), respectively. The temperature increase in the roadway can then be predicted using psychrometric equations (Jones and Browning, 1974).

The surface temperature given by Voss (1969) is,

$$T_s = T_B + \frac{K_{eff}}{h_{eff}} \frac{T_R - T_B}{r_0} T'(Fo,Bi) \tag{2.4}$$

where T_B = the base temperature (°C)

K_{eff} = the effective thermal conductivity (W/m)

h_{eff} = the effective heat transfer coefficient (W/m^2)

T_R = the virgin strata temperature (°C)

r_0 = the radius of the roadway (m)

$T'(Fo,Bi)$ = the temperature gradient

The dry heat flux, F_D, and the wet heat flux, F_W, through a partially wetted airway can be calculated using equations (2.5) and (2.6), respectively.

$$F_D = h \cdot (1-f) \cdot (T_{sD} - T_D) + fh(T_{sW} - T_D) \tag{2.5}$$

$$F_W = \frac{f\beta r_v}{RT}[P_s(T_{sW}) - P_{air}] \tag{2.6}$$

where h = the heat transfer coefficient at roadway surface (W/m^2)

f = the wetness factor

T = the temperature (°C)

P = the pressure (Pa)

β = the mass transfer coefficient (m/s)

R = the gas constant (J/kg K)

s = surface

D = dry

W = wet

Equivalent thermal conductivity (K_{eq}) will be used in equation (2.4) instead of the thermal conductivity (K_{eff}) of the strata when calculations are made for the heat from all other heat sources in a roadway.

After the theoretical work for predicting air temperatures in roadways had been completed by Voss (1969), work was continued in order to determine the thermal parameters, the equivalent thermal conductivity and the wetness factor, for underground roadways and faces. In addition, climatic surveys were conducted with continuous recorders. From these surveys, Voss (1970) found that different equivalent thermal conductivities were obtained for intake and return roadways, conveyor and conveyorless gateroads, and workings with advance and retreat headings. High wetness factors were obtained from places where water infusion equipment was used. Moreover, both the equivalent thermal conductivity and the wetness factor varied with the rate of coal output.

Mucke and Voss (1971) investigated methods to improve mine climate in deep and mechanised faces, and also discussed on the temperature limits for underground workings in Europe.

Since Voss (1970) concluded that the thermohygrograph, which is a mechanical device for continuously measuring temperatures and humidity, was not accurate enough for his work, a new device was developed for continuously recording temperature and humidity in mines. This is called the Sina instrument and was tested and calibrated by Weuthen and Chatel (1971). It has never been used in British coalmines because of the safety regulation in Britain. According to Burrell (1989), the instrument does not provide accurate measurements of humidity.

Marzilger and Wagner (1972) improved Voss' computer programme, which is the StBV programme, for climate prediction. They provided procedures for calculating the age coefficient instead of using tables of age coefficients. The procedures can be programmed in Fortran. In addition, they investigated the errors, which occur during derivation, and made assessments of the possible errors in the computation, of the age coefficient. In the process of evaluating the age coefficient, five errors are pointed out. These errors are as follows:

(i) Integration error - This is due to the fact that the age coefficient is an integral and it has a singularity point at the origin. The integral cannot therefore be integrated from its lower limit, 0, and a small number, say N, has to be used for the integration of the integral.

(ii) Truncation error - This occurs when limited terms of a polynomial are assumed.

(iii) Simpson error - Simpson rule is a numerical integration method and the integration of an integral using this method will inevitably include errors due to the numerical integration.

(iv) Bessel function error - The Bessel functions in the age coefficient are represented in terms of power series. Since the power series cannot be exactly the same as the function itself, error is produced.

(v) Rounding off error - This error is obvious in that all the numerical work can only be conducted within a limited number of significant figures.

Heat from conveyed coal has always been recognised as an important heat source in mines. It began to draw more attention as coal output increased rapidly from the seventies onward. For this reason, it becomes necessary to calculate heat from conveyed coal and strata separately.

Hermanns (1976) developed a computer programme incorporating a graphical method to calculate the heat and moisture emissions from conveyed coal. This graphical method was developed by Voss (1965). The model treats the conveyed coal as a continuous slab with a partially wetted surface. From the computed results of the heat emitted by conveyed coal in a conveyor roadway, Hermanns (1976) showed that the conveyor roadway increased, over the length of the roadway, in temperature by 1.8 °C in the dry bulb and 2.7 °C in the wet bulb, due to the heat emitted from the conveyed coal production at a rate of 288 t/hour.

Schlotte (1980) undertook investigations of the climate in German coalmines, and showed that conveyed coal could have a significant effect on air temperatures. He then commented that an experimental rig to study the heat and moisture emissions from the conveyed coal to the air stream was being developed. It was not until 1987 that Schlotte (1987) produced results of tests conducted on conveyed coal. He considered the relationships between the heat transfer coefficients and the air velocity, the cooling of the conveyed coal with time, and the wetness of the coal and the rate of moisture evaporation at the coal surface. The conclusion made for the relationship between the moisture content of the coal and the rate of evaporation, was that the rate of evaporation from the surface of the conveyed coal was independent of the moisture content of the coal. The equivalent thermal conductivity of conveyed coal was found to be within a range of 0.16 to 2.8 W/mK. This variation is caused by the random grain size distribution and the varying bulk density of the coal.

2.2.3 The British Approach

At the Mining Research and Development Establishment (MRDE), Bretby, Hitchcock and Jones (1958) began investigations of heat flow in a main intake roadway. Hitchcock and Jones (1958) assumed that radial heat flow occurred in the roadway. They also assumed a boundary condition given by Newton's Law of cooling. With the aid of Jaeger's (1942) results, the strata surface temperature was found. The heat flux from strata could then be calculated.

In addition to their theoretical work, Hitchcock and Jones (1958) measured how strata temperature distributions varied with time (see Figure 2.3) by measuring temperatures in seven 12 ft long boreholes driven into roadway strata at three points along a main intake roadway in Llay Main Colliery. These temperature measurements allowed Hitchcock and Jones (1958) to compare their experimental results with their own theoretical work and that of, de Braaf(1951), and Ingersoll et al (1954).

They compared surface temperature, thermal conductivity, thermal diffusivity, heat transfer coefficients and the rate of heat flow into the roadway. From these comparisons, Hitchcock and Jones (1958) concluded the following.

(1) For theoretical work, the roadway can be considered as an internally bounded circular cylinder within a homogeneous dry medium.

(2) The thermal resistance at the boundary (approximately equal to a foot of rock) was negligible compared to that of the surrounding strata, except in the initial cooling stages.

(3) The theoretical predictions of the temperature rise along the roadway were slightly higher than the observed values. This discrepancy is due to the fact that the effect of water evaporation had not been taken into account.

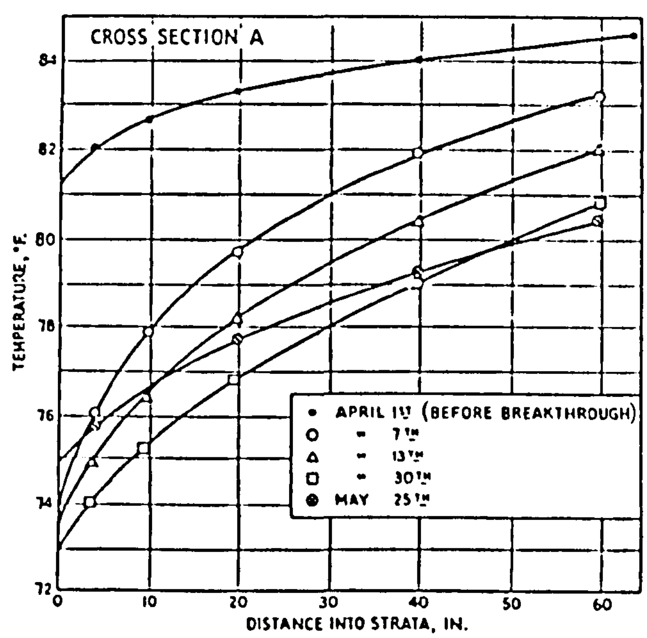


Figure 2.3 Temperature in the Sides and Roof of the roadway (Hitchcock and Jones, 1958)

Hitchcock et al (1959, 1960, 1967) continued the work by developing an experimental rig to study the heat flow in strata under laboratory conditions. This development was suggested by Hitchcock and Jones (1958), who found difficulties in measuring strata temperature, over a long period, after the roadway had been cooled by ventilation air. An experimental model was built which could provide a strata cooling time of one year in 5.7 hours. This meant that it was possible to observe the temperature change of the strata, and hence the heat flow, in a much shorter time.

During this period, Jordan (1960, 1961) developed a numerical method for solving some boundary value problems in heat conduction, by means of convolution integrals. The method was first used to calculate the surface temperature of a semi-infinite solid with different boundary conditions. The results of these calculations were then compared with the existing analytical solutions, and satisfactory agreements was obtained. The calculations were extended to find the surface temperature of an internally bounded circular cylinder, and again, satisfactory agreement between the solution obtained from the numerical method and the analytical solution was obtained.

Since Jordan (1961) obtained satisfactory results using the numerical method, the method was used to calculate the surface temperature of a dry roadway (Jordan, 1965a) from which, the heat flux from strata could be found. Sharp et al (1965) later used the same method to calculate the heat flow in roadway headings, and these calculations were extended to include the heat flow in a partially wetted heading (Jordan, 1965b).

Nendzki (1962) used a Crank Nicolson method to solve the problem of heat flow from strata. This method is basically a finite difference method for solving partial differential equations.

During the seventies, MRDE began investigating the factors which cause climate problems in mines. Instead of concentrating on the development of a mine climate prediction programme, they adopted the StBV programme developed by Voss

(1969) to calculate the heat flow from strata. Browning et al (1977) later concluded that the programme would produce higher values for strata heat emission because it is based on steady state solutions for calculating heat flow from strata, in that the air temperature is assumed to remain constant over the ventilated age of the airway.

Since Browning et al (1977) concluded that the StBV programme would predict higher heat emission from strata than actually took place, a search for a transient technique to calculate the transient heat flow from strata was then undertaken by MRDE. Westwood (1979) showed how a finite element technique could be used for solving the Heat Diffusion Equation with non-linear boundary conditions.

Palin (1983) reviewed the work done by Jordan (1961) and the model developed by Voss (1969). He then developed a hybrid technique to calculate the transient heat flow from strata. This technique uses the steady state method to calculate the surface temperature of the roadway prior to the production week and the transient method of Jordan (1961) to calculate the surface temperature during the production week. The surface temperature given by Palin (1983) is,

$$\phi(0,m) = \phi(\infty,0) - f_0 I_m - \sum_{s=1}^{m'} I_{m-s+1} \Delta'_s(f) - \sum_{s=m'+1}^{m} I_{m-s+1} \Delta''(f) \qquad (2.7)$$

where
- $\phi(0,m)$ = surface temperature at t = m. dt (°C)
- $\phi(\infty,0)$ = initial temperature at t = 0 (strata temperature °C)
- f(t) = heat flux function (W/m²)
- I(t) = integral given by Jordan (1961)

The surface temperature at time, t, is given by 4 terms in equation (2.7), the first term is the virgin strata temperature, the second and third terms are the contribution to the heat flux during past history and the fourth term is the contribution during the production week. In order to have a smooth transition from steady state to transient state, Palin (1983) added a conditioning week, which is to be included in the fourth term, prior to the production.

Palin (1983) also investigated techniques for calculating the heat from conveyed coal. He adopted the graphical method developed by Voss (1965).

A computer programme incorporating the mathematical models of the transient heat flow from strata and the heat from conveyed coal was developed for climate predictions by Palin (1983). This programme also included empirical equations developed by Browning et al (1982) for calculating the heat from machinery and the Lump Capacity Method for calculating the heat storage in structural steel. Unfortunately, this programme has not been tested thoroughly, and the subroutine for the heat from the conveyed coal has not been completed.

Palin's technique for calculating the transient heat flow from strata was later adopted by Burrell and Maneylaws (1985). They used the method to calculate the transient heat flow from strata in mine roadways, and a finite element method was used for the face calculation (Burrell et al, 1988). The surface temperature given by Burrell and Maneylaws (1985) is the same as Palin (1983). The heat flux, F(t), given by Burrell and Maneylaws (1985) is,

$$F(t) = h[\phi(0,t) - \theta(t)] + \frac{f\beta L}{RT}\{P[\phi(0,t)] - P_{air}(t)\} \qquad (2.8)$$

where	h	=	the heat transfer coefficient (W/m^2)
	f	=	the wetness factor
	L	=	the latent heat of evporation (J/kg K)
	R	=	the gas constant for air (J/kg K)
	P	=	the pressure (Pa)

T	=	the absolute surface temperature (K)
β	=	the mass transfer coefficient (m/s)
$\phi(0,t)$	=	the surface temperature (°C)
$\theta(t)$	=	the dry bulb temperature of air (°C)

A finite element technique was also proposed for modelling the heat flow in the heading (Burrell et al, 1988).

2.2.3.1 Mine climate research at Nottingham University

The Department of Mining Engineering of Nottingham University began their interest in mine climate prediction during the seventies.

Gibson (1976) developed a computer model for predicting air temperature in mine roadways. This model was similar to the model developed by Voss (1969). The mine roadway was also assumed to be cylindrical and surrounded by homogeneous rock. Apart from calculating the heat flow from strata, the computer programme has a facility for entering the electrical power consumption, so that the heat from machinery can be estimated. In addition, a subroutine was developed for calculating the temperature of the air mixed at junctions. This is an important subroutine in the programme because it enables the programme to be developed for network analysis of air temperature (Gibson, 1977).

Gibson's work was continued by Middleton (1979). He applied the programme to predict air temperatures in mine workings.

Heat from conveyed coal was investigated by Watson (1982). An experimental rig was built to determine the thermal parameters of coal with given moisture contents. The results from the experiments were related to air velocity. On site measurements of conveyed coal temperature were also attempted by Watson. He felt, however, that there were too many variables in the mine to enable reasonable, accurate measurements to be made.

At the same time, a methane prediction programme was developed by Kolada (1982), and the effect of the recirculation of mine air on the air flow in deep mines was studied by Stokes (1982).

In 1984, the Mining Department of Nottingham University was awarded a European Coal and Steel Community research grant to study the recirculation of mine air with particular attention to transients. The research was divided into three areas; (i), airflow in deep mines, (ii), methane emission, and (iii), mine climate prediction.

The climate prediction programme for mine roadways originally developed by Gibson (1976), included the heat flow models for strata and conveyed coal. The model for the heat flow from conveyed coal is given by equation (2.9),

$$Q = \frac{45 \cdot l}{1000}(T_R - 1 - T_D) \tag{2.9}$$

where

where	Q	=	heat from conveyed coal (W)
	l	=	length of conveyed coal (m)
	T_R	=	virgin rock temperature (°C)
	T_D	=	dry bulb temperature of air (°C)

This equation may be an oversimplification. It assumes that the temperature of the conveyed coal is 1 °C below the strata temperature. This assumption may be unsound. The coal temperature could be higher than the strata temperature because the cut coal could be heated due to friction from the cutting process, and if the strata temperature was lower than the air temperature, the coal could also be heated up by the ventilation air.

A climate prediction program for faces was developed by Tuck (1986). The face is assumed to be a rectangular opening, and the heat flow from the strata in the face is assumed to be one dimensional. The use of the programme was demonstrated by Jack and Tuck (1988).

Research has continued in the field of mine climate at the Department of Mining Engineering at Nottingham University. Three Ph.D's (Longson, 1986; Jones, 1987 and Jack, 1987) were completed in the field of recirculation of mine air.

2.2.4 Rest of the World Approach

Heat and humidity used not to be a problem for mines in Australia, Japan, the U.S.A., and in countries which traditionally have shallow mines. However, this situation has been changing recently as newer workings are at greater depths, in hotter strata. There is therefore an increased requirement for better working environments.

2.2.4.1 Mine climate work in Australia

During the seventies, Vost (1973, 1974, 1976, 1975) investigated the techniques used to measure in-situ values of the heat transfer coefficient, thermal conductivity, and thermal diffusivity. In addition, the effect of air temperature variation on mine climate prediction work was discussed.

In-situ measurements of thermal conductivity made by Vost (1973) agreed closely with laboratory results. In-situ measurements of heat transfer coefficients (Vost, 1974) gave good agreement with those derived from Starfield's (1969) theoretical method, providing the surface roughness assumed in the theoretical model was within the range 1.65 to 1.7.

An empirical method similar to those developed by Lambrechts (1967) and Jones and Browning (1974) was developed by Vost (1975) to predict wet bulb temperature gradients for Australian mine shafts.

Investigations of the effect of air temperature variation in mines were undertaken by Vost (1976, 1977). Vost (1976) made observations of the temperature variation at the cross section of a roadway, and Vost (1977) studied the air temperature variation along a mine roadway. The conclusions made from these investigation are, (i), air temperatures vary from the floor to the roof of a roadway, and (ii), a large change in air temperature can cause a substantial change in the temperature gradient at the roadway surface. Hence, air temperature could affect the rate of heat flow from strata.

Vost (1979) had different view from Gracie and Matthew (1975) on the effect of heat storage in structural steel. Vost (1979) adopted a theoretical approach, which showed that the heat stored in the structural steel would have little effect on air temperatures in an underground roadway. On the other hand, Gracie and Matthew (1975) suggested that the heat absorbed by the structural steel had a considerable effect on the air temperature.

Vost continued his mine climate work at the Chamber of Mines in South Africa where he compared the climate prediction program developed by Starfield (1969), and Gibson (1976).

2.2.4.2 Mine climate work in France

The StBV programme developed by Voss (1969) for climate predictions became very popular in Europe during the seventies.

The programme was tested by d' Albrand and Profizi (1980). They undertook site investigations to determine the equivalent thermal conductivity and the wetness factor for roadways and faces. The results of these measurements were used to produce temperature predictions using the StBV programme. The conclusions made from the predicted temperature are that, at most points, the difference between the predicted temperature and the actual temperature is less than 1 °C, but that at the inbye end of the gateroad, the difference is 3.8 °C. An attempt was made to reduce the temperature difference at the inbye end of the gateroad by altering the thermal parameters, equivalent thermal conductivity and wetness factor, at the input, and this only reduces the difference between the predicted temperature and the actual temperature by 2 °C at the output.

2.2.4.3 Mine climate work in India

The computer programme developed by Amano et al (1982), see following sections, was examined by Misra (1987) in India. Temperature predictions were made using the techniques developed by Amano et al (1982). Comparison between the actual temperature and the predicted temperature, made by Misra (1987), produce no definite conclusion, in that some predicted temperatures showed good agreement with the actual temperatures but some predicted temperatures differed from actual temperatures by several °C.

2.2.4.4 Mine climate work in Japan

A mine climate prediction programme was developed by Hiramatsu and Amano (1972). The computer model consisted of two sub-systems; the first calculated the rate of airflow using network analysis and the second calculated the heat and humidity in mine airways. In the second sub-system, the method used to calculate the heat from strata assumed that the air temperature variations were small.

This climate prediction programme was improved by Amano et al (1982). They used a two surface model to represent the roadway, one a dry surface and the other a wet surface. The technique used to calculate the heat flow from the strata involves obtaining the heat flux from the dry surface via a method similar to that of Hitchcock and Jones (1958). A finite difference method is used to calculate the heat flux from the wet surface.

Amano et al (1988) investigated how the in-situ thermal properties of rock in mine roadways can be determined. The technique, which they used, is similar to that of Hitchcock and Jones (1958), and Vost (1975).

2.2.4.5 Mine climate work in U.S.A.

Starfield (Starfield and Bleloch, 1983; Mack and Starfield, 1985) continued his mine climate work in United States. He and Bleloch (Starfield and Bleloch, 1983) developed a theoretical method for calculating the heat and moisture transfer from a partially wetted airway. This is a two surface model. The assumptions made are that the roadway is cylindrical and surrounded by homogeneous rock. The surface temperature for the dry and wet surface can be found using the mathematical technique detailed by Starfield and Bleloch (1983), and hence, the heat flux from the strata can be calculated. The method is subject to errors, in that heat conduction between the dry surface and wet surface can take place because the surface temperature on the wet surface is lower than the dry surface.

A Fortran programme (Cheung, 1987) was developed from the algorithm given by Starfield and Bleloch (1983). The programme was tested by Cheung (1988) at the Department of Mining Engineering, University of Newcastle upon Tyne, England. Qualitative agreement was obtained between the predicted temperature and the air temperature at the end of a roadway. However, the technique is not suitable for modelling the transient heat flow from strata because the technique is based on the solution of the Laplace equation, which is a time independent equation.

A different approach was adopted by Mack and Starfield (1985) for calculating heat flow from strata in a roadway. They used the Duhamel Theorem to model the transient heat flow from strata, and compared the predicted transient temperatures to those predicted by Starfield and Bleloch (1983).

Mousset-Jones and McPherson (1983) conducted investigations on the design parameters necessary for improving mine climate in the United States. They compared the available computer models for predicting air temperatures in mines, undertook investigations of the in-situ thermal rock properties (Mousset-Jones et al, 1986; Danko et al 1987 and 1988), and developed a mathematical method to calculate heat flow in mines (McPherson, 1986).

A computer Programme called Climsim was developed by McPherson (1986) for predicting air temperatures in a mine roadway. The model assumes that the roadway is made up of two surfaces, one dry and the other partially wetted. The calculation of the surface temperature of the roadway, and the heat flux into the airway, uses the same method developed by Voss (1969). The Climsim programme (McPherson, 1986) is different to Voss (1969) because instead of using equivalent thermal conductivity to calculate the heat flux from all the heat sources in the roadway, heat flux from individual heat sources are calculated. The sum of individual heat fluxes is then used to calculate the temperature rise in the roadway.

2.3 SUMMARY

Mine climate in deep mines has been studied by many people around the world in the last three decades. Although the approaches to the study of mine climate undertaken by the research establishments in different countries are different from each other, they fall into four main areas.

(i) Development of mathematical methods to calculate the heat flow from strata and conveyed coal, and of empirical equations for calculating the heat from machinery.

(ii) Development of computer software, incorporating the mathematical model as described in (i), to produce temperature predictions.

(iii) To undertake climate investigations to determine the in-situ thermal property of strata and conveyed coal in underground mines, and compare the in-situ results with those obtained from laboratory experiments.

(iv) To investigate methods for planning and controlling mine climate using the software developed in (ii).

CHAPTER THREE

STRATA HEAT

Climatic investigations undertaken by Browning et al (1977 and 1980), Whittaker (1980) and Schlotte (1980) showed that the heat emitted by strata accounts for 70 - 80 % of the total heat emission in a longwall district. It is therefore necessary to calculate the heat flow from strata accurately in order to make good temperature predictions for mines.

Heat flow between the surrounding strata and the ventilation air in a mine roadway consists of two heat transfer processes. The first is heat conduction through strata ,and the second is heat convection by the ventilation air at the roadway wall. The rate of heat flowing between these two media depends on the virgin strata temperature, and how quickly the strata is being cooled by the ventilation air.

The factors affecting the heat conduction through the strata are as follows:

(i), virgin strata temperature,

(ii), physical properties of the rock,

(iii), previous history of strata cooling and heating,

and (iv), non-homogeneity of the strata.

The factors affecting the rate of strata cooling by the ventilation air are as follows:

(i), humidity and temperature of the air,

(ii), air velocity,

(iii), evaporation and condensation of moisture at the roadway surface,

(iv), size, shape and surface roughness of the roadway,

and (v), emissivity of the rock surface.

Many people have been engaged in the development of the mathematical techniques used to calculate the heat flow from strata. These techniques include those developed by Goch and Patterson (1940), Hitchcock and Jones (1958), Starfield (1966b), Voss (1969), Amano et al (1972, 1982), Palin (1983), Starfield et al (1983, 1985), Burrell and Maneylaws (1985), and Cheung (1989).

The assumptions made by these models are that:

(i), the roadway is a circular cylinder,

(ii), heat conduction parallel to the direction of the roadway is negligible when compared with the heat flow in the radial direction,

(iii), the roadway strata is homogeneous and isotropic,

and (iv), the roadway can be divided into small lengths.

In addition, Goch and Patterson (1940), Hitchcock and Jones (1958), Starfield (1966b) and Jordan (1965) assumed that the roadway surface was completely dry.

The mathematical models which have been developed can be divided into steady-state and transient models. The steady-state models include those developed by Goch and Patterson (1940), Hitchcock and Jones (1958), Starfield (1966b), Voss (1969), Amano et al (1972, 1982), Starfield and Bleloch (1983) and McPherson (1986). The transient models are based on the Duhamel Theorem (Carslaw and Jaeger, 1959), and include the models developed by Jordan (1965), Palin (1983), Burrell and Maneylaws (1985), Starfield (1985) and Cheung (1989).

3.1 STEADY-STATE MODEL

In the steady state models, the heat conduction process in strata can be described by a two dimension Heat Diffusion Equation in polar form.

$$\frac{1}{\alpha}\frac{\partial V}{\partial t}=\frac{\partial^2 V}{\partial r^2}+\frac{1}{r}\frac{\partial V}{\partial r} \tag{3.1}$$

where $V=V(r,\theta,t)$

$\alpha=$ thermal diffusivity

Taking the Laplace Transform (Stephenson, 1980 and 1982) of equation (3.1) gives,

$$\frac{1}{\alpha}[s\cdot\bar{v}(r,s)-V(r,0)]=\frac{d^2\bar{v}}{dr^2}+\frac{1}{r}\frac{d\bar{v}}{dr} \tag{3.2}$$

where $\bar{v}=$ the Laplace Transform of V in t

$\bar{v}=\int_0^\infty e^{-St}f(t)dt$

Putting $q^2=s/\alpha$, equation (3.2) can be written in the standard form of a modified Bessel equation,

$$\frac{d^2\bar{v}}{dr^2}+\frac{1}{r}\frac{d\bar{v}}{dr}-q^2\bar{v}=\frac{-V(r,0)}{\alpha} \tag{3.3}$$

In order to solve equation (3.3), the initial and boundary conditions of the physical problem must be specified.

3.1.1 Single Surface Model

Goch and Patterson (1940) assumed the initial temperature for the strata was the virgin strata temperature, v_0. They also assumed infinite heat transfer at the roadway surface. This gives,

$$V(r,0) = v_0 \quad \text{for} \quad r > a \tag{3.4a}$$

$$V(r,t) = v_1 \quad \text{for} \quad r = a \tag{3.4b}$$

where v_1 = the air temperature (°C)

Substituting the initial boundary condition (3.4a) into equation (3.3) gives,

$$\frac{d^2\bar{v}}{dr^2} + \frac{1}{r}\frac{d\bar{v}}{dr} - q^2\bar{v} = \frac{-v_0}{\alpha} \tag{3.5}$$

The general solution of equation (3.5) is,

$$\bar{v} = AI_0(qr) + BK_0(qr) + \frac{v_0}{s} \tag{3.6}$$

where I_0 and K_0 = the modified Bessel functions of order zero,

and, A and B = the constants of the integration

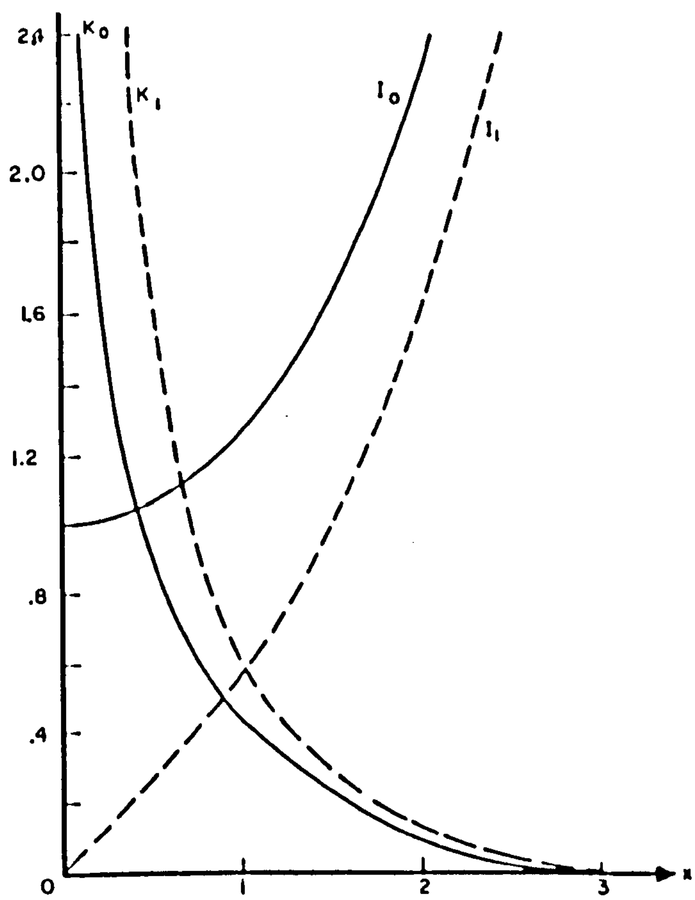


Figure 3.1 $I_0(x)$, $K_0(x)$, $I_1(x)$, $K_1(x)$

The function I_0 and K_0 are shown in Figure 3.1. It can been seen from Figure 3.1 that A must be zero for real solutions of equation (3.5). Equation (3.6) then becomes,

$$\bar{v}(r,s) = BK_0(qr) + \frac{v_0}{s} \tag{3.7}$$

Taking the Laplace transform of the boundary condition, equation (3.4b), and substituting that into equation (3.7) gives,

$$\frac{v_1}{s} = BK_0(qa) + \frac{v_0}{s} \tag{3.8}$$

which may be rearranged to,

$$B = \frac{(v_1 - v_0)}{s}\frac{1}{K_0(qa)} \tag{3.9}$$

Substituting B back into equation (3.7) gives,

$$\bar{v}(r,s) = \frac{(v_1 - v_0)}{s}\frac{K_0(qr)}{K_0(qa)} + \frac{v_0}{s} \tag{3.10}$$

The Inverse Transform of equation (3.10) given by Carslaw and Jaeger (1959, p. 335) is,

$$V(r,t) = v_0 + (v_1 - v_0) + \frac{2(v_1 - v_0)}{\pi}\int_0^\infty e^{-\alpha u^2 t}\frac{J_0(ur)Y_0(ua) - Y_0(ur)J_0(ua)}{J_0^2(ua) + Y_0^2(ua)}\frac{du}{u} \tag{3.11}$$

where J_0 and Y_0 = the Bessel functions of order zero.

Simplifying equation (3.11) gives,

$$V(r,t) = v_1 + \frac{2(v_1 - v_0)}{\pi}\int_0^\infty e^{-\alpha u^2 t}\frac{J_0(ur)Y_0(ua) - Y_0(ur)J_0(ua)}{J_0^2(ua) + Y_0^2(ua)}\frac{du}{u} \tag{3.12}$$

Differentiation of equation (3.12) to obtain the temperature gradient at r = a produces,

$$\left(\frac{dV}{dr}\right)_{r=a} = \frac{-2(v_1 - v_0)}{\pi}\int_0^\infty e^{-\alpha u^2 t}\frac{J_1(ua)Y_0(ua) - Y_1(ua)J_0(ua)}{J_0^2(ua) + Y_0^2(ua)}\frac{du}{u} \tag{3.13}$$

Since $J_1(z)\,Y_0(z) - J_0(z)\,Y_1(z) = 2/\pi z$ (Abramowitz and Stegun, 1972), equation (2.13) can be written as,

$$\left(\frac{dV}{dr}\right)_{r=a} = \frac{4(v_0 - v_1)}{\pi^2 a}\int_0^{\infty} \frac{e^{-\alpha u^2 t}}{J_0^2(ua) + Y_0^2(ua)}\frac{du}{u} \tag{3.14}$$

Hence, the heat flux, F, is,

$$F = K\frac{dV}{dr} = \frac{4K}{\pi^2 a}(v_0 - v_1)\int_0^{\infty} \frac{e^{-\alpha u^2 t}}{J_0^2(ua) + Y_0^2(ua)}\frac{du}{u} \tag{3.15}$$

Equation (3.15) was also given by Goch and Patterson (1940) for the calculation of the heat flux from strata. Furthermore, a table which gives approximate values for the integral in equation (3.15) was produced by Goch and Patterson (1940). This table provides quick solutions for the heat flux from a circular cylinder with a given radius.

3.1.1.1 An improved technique

Hitchcock and Jones (1958), and Starfield (1966b), considered the same problem considered by Goch and Patterson (1940), but used a different boundary condition at the roadway surface. Hitchcock and Jones (1958) and Starfield (1966b) considered that heat convection was taking place at the roadway wall. This means that the heat flow between the surface and the ventilation air is proportional to the temperature difference between the surface temperature of the roadway strata and the ventilation air temperature. Thus, the boundary condition is more complex than the one assumed by Goch and Patterson (1940). Moreover, it is more appropriate because its representation of the physical problem is closer to reality.

The technique used by Hitchcock and Jones (1958) to find the surface temperature is different from that used by Starfield (1966b). Hitchcock and Jones

(1958) produced an analytical solution for finding the surface temperature of the roadway strata, and Starfield (1966b) used a finite difference method. There is an advantage in using the analytical solution because the errors are reduced in the calculation of the surface temperature, whereas numerical approximation inevitably introduces rounding off errors in the finite difference method.

Since Hitchcock and Jones (1958) considered the same problem as Goch and Patterson (1940), the general solution, equation (3.7) of the Heat Diffusion Equation (3.1) can be used. The boundary condition for the heat convection at the roadway wall is,

$$K\left(\frac{\partial V}{\partial r}\right)_{r=a} = h(V - v_1) \tag{3.17}$$

where	a	=	the radius of the roadway (m)
	v_1	=	the air temperature (°C)
	K	=	the thermal conductivity of the strata (W/m)
	h	=	the convective heat transfer coefficient (W/m²)

Taking the Laplace Transform of equation (3.17) gives,

$$K\left(\frac{dV}{dr}\right)_{r=a} = h\left(\bar{v} - \frac{v_1}{s}\right) \tag{3.18}$$

Differentiation of equation (3.7) gives,

$$\frac{d\bar{v}}{dr} = -BqK_1(qr) \tag{3.19}$$

where K_1 = the modified Bessel function of order 1

Substituting the transformed boundary condition, equation (3.18), into equation (3.19) gives,

$$-BKqK_1(qa) = h \cdot \left[\left(BK_0(qa) + \frac{v_0}{s} \right) - \frac{v_1}{s} \right] \tag{3.20}$$

which may be rearranged to give,

$$B = \left(\frac{v_1 - v_0}{s} \right) \frac{(\frac{h}{K})}{qK_1(qa) + (\frac{h}{K})K_0(qa)} \tag{3.21}$$

Substituting B into equation (3.7) gives,

$$\bar{v}(r,s) = \frac{(v_1 - v_0)}{s} \frac{(\frac{h}{K})K_0(qr)}{qK_1(qa) + (\frac{h}{K})K_0(qa)} + \frac{v_0}{s} \tag{3.22}$$

Equation (3.22) can also be written as,

$$\bar{v}(r,s) = \frac{v_1}{s} - \frac{(v_1 - v_0)}{s} \left[1 - \frac{(\frac{h}{K})K_0(qr)}{qK_1(qa) + (\frac{h}{K})K_0(qa)} \right] \tag{3.23}$$

The Inverse of equation (3.23) given by Carslaw and Jaeger (1959, p.337) is,

$$V(r,t) = v_1 + \frac{2(\frac{h}{K})(v_1 - v_0)}{\pi} \int_0^\infty e^{-\alpha u^2 t} \frac{J_0(ur)[uY_1(ua) + (\frac{h}{K})Y_0(ua)] - Y_0(ur)[uJ_1(ua) + (\frac{h}{K})J_0(ua)]}{[uJ_1(ua) + (\frac{h}{K})J_0(ua)]^2 + [uY_1(ua) + (\frac{h}{K})Y_0(ua)]^2} \frac{du}{u} \tag{3.24}$$

By substituting r = a into equation (3.24), the surface temperature of the strata is,

$$V(r,t) = v_1 + \frac{2(\frac{h}{K})(v_1 - v_0)}{\pi}\int_0^{\infty} e^{-\alpha u^2 t}\frac{u[J_0(ua)Y_1(ua) - Y_0(ua)J_1(ua)]}{[uJ_1(ua) + (\frac{h}{K})J_0(ua)]^2 + [uY_1(ua) + (\frac{h}{K})Y_0(ua)]^2}\frac{du}{u} \tag{3.25}$$

Since $J_1(z)\,Y_0(z) - J_0(z)\,Y_1(z) = 2/\pi z$ (Abramowitz and Stegun, 1972), equation (3.25) can be written as,

$$V(r,t) = v_1 + \frac{4(\frac{h}{K})(v_1 - v_0)}{a\pi}\int_0^{\infty} \frac{e^{-\alpha u^2 t}}{[uJ_1(ua) + (\frac{h}{K})J_0(ua)]^2 + [uY_1(ua) + (\frac{h}{K})Y_0(ua)]^2}\frac{du}{u} \tag{3.26}$$

Letting $Fo = \alpha t / a^2$ and $Bi = a h / K$. equation (3.26) becomes,

$$V(a,t) = v_1 - (v_0 - v_1)\frac{4}{\pi^2}\int_0^{\infty}\frac{e^{-Fo\,a^2 t}}{\left[Bi^{-\frac{1}{2}}uaJ_1(ua) + Bi^{\frac{1}{2}}J_0(ua)\right]^2 + \left[Bi^{-\frac{1}{2}}uaY_1(ua) + Bi^{\frac{1}{2}}Y_0(ua)\right]^2}\frac{d(ua)}{(ua)} \tag{3.27}$$

As the integral is only a function of Fo and Bi, equation (3.27) can be written as,

$$V(a,t) = v_1 + (v_0 - v_1)I(Fo,Bi) \tag{3.28}$$

where $I(Fo,Bi) = \frac{4}{\pi^2}\,(\text{integral})$

The integral in equation (3.28) was evaluated and plotted with Fo against different values of Bi, by Jaeger (1942). Equation (3.28) is also given by Starfield (1966b) for finding the surface temperature. In addition, a table which gives approximate values for the integral was produced by Starfield (1966b). The table is similar to the one produced by Goch and Patterson (1940) and it allows a manual calculation to be made in order to find the surface temperature of the roadway strata.

3.1.2 Two Surface Model

The mathematical model developed by Voss (1969), Amano et al (1982), Starfield and Bleloch (1983) and McPherson (1986) considered the roadway to be made up of two surfaces, one surface being completely dry and the other partially wetted. The degree of wetness of the roadway is described by a wetness factor. This factor is the ratio of the area of the wet surface to the total surface area. That is,

$$\eta_f = \frac{\text{area of wet surface}}{\text{total area of roadway surface}} \tag{3.29}$$

where η_f = a dimensionless wetness factor

Voss (1969) and McPherson (1986) used similar techniques to calculate the heat flow from strata in a roadway. The difference between the two techniques is that Voss (1969) included the heat emitted by other heat sources in the roadway. Voss (1969) considers that the heat from other heat sources in the roadway is equivalent to the heat from strata so that the heat from the other heat sources can be calculated using the equations developed for the calculation of strata heat flow. McPherson (1986) only used the technique to calculate the heat from strata. Amano et al (1982) used the method developed by Hitchcock and Jones (1958) to calculate the surface temperature of the dry surface and a finite difference method to calculate the surface temperature of the wet surface. Starfield and Bleloch (1983) used a completely different approach. They applied the solution of the Laplace equation to find the surface temperatures around a cylindrical roadway. The wet surface described in this model is a sector of the roadway subtending at an angle of 2β (Figure 3.2) to the centre of the roadway. The method was studied in detail by Cheung (1987), who considered the model as unsuitable for further development for transformation into a transient model because the Laplace equation does not use a time variable.

Since Voss' (1969) technique is currently used by British Coal, U.K. and other European companies (d'Albrand and Profizi, 1980), and also by Maughan (1988) for his development of a steady state computer model for mine climate predictions, the technique developed by Voss (1969) will be discussed in detail for comparison with the transient solution obtained herein from the transient analysis using the Duhamel Theorem.

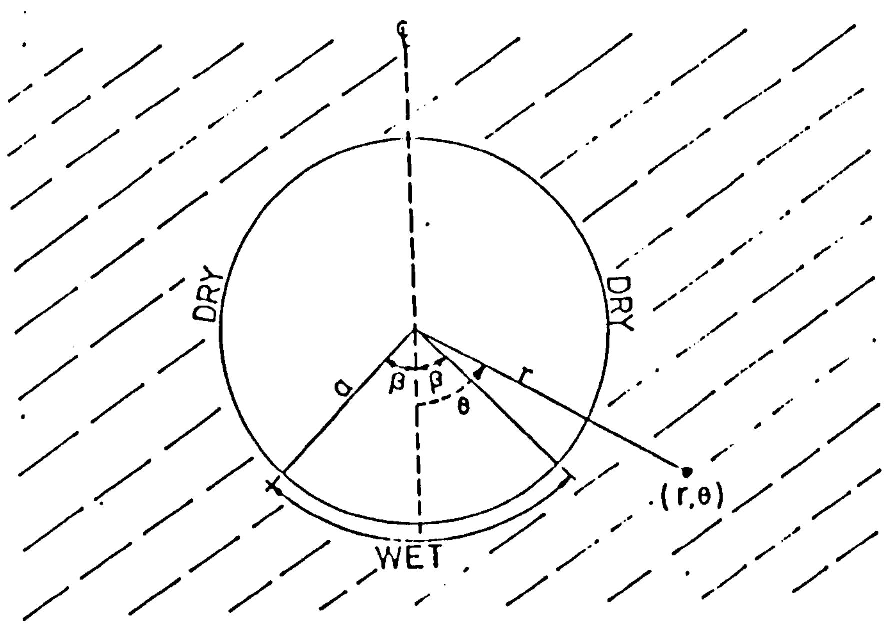


Figure 3.2 Geometry assumed by Starfield and Bleloch (1983) for the cross section of an airway

The surface temperature given by Voss (1969), is,

$$V(a,t) = v_1 + \frac{K_{eff}}{ha}(v_0 - v_1)K(\alpha) \tag{3.30}$$

where K_{eff} = effective thermal conductivity (W/m)

h = heat transfer coefficient (W/m²)

$K(\alpha)$ = the age factor

Comparison between the equation (3.30) and equation (2.26) given by Hitchcock and Jones (1958), shows that,

$$I(Fo,Bi) = \frac{K_{eff}}{ha}K(\alpha) \tag{3.31}$$

where Fo = the Fourier number

Bi = the Biot number

It can be seen from equation (3.31) that the equations developed by Voss (1969) for the calculation of the surface temperature of roadway strata are similar to those developed by Hitchcock and Jones (1958) providing equation (3.31) is satisfied.

The age factor derived by Marzilger and Wagner (1972) is,

$$K(\alpha) = \left(\frac{2}{\pi}\right)^2 \int_0^\infty \frac{e^{-x^2 Fo}\ dx}{x\left\{[I_0(x) + \frac{x}{Bi} I_1(x)]^2 + [Y_0(x) + \frac{x}{Bi} Y_1(x)]^2\right\}} \tag{3.32}$$

By taking a factor of $(Bi)^{1/2}$ out from both the brackets in equation (3.32), equation (3.32) can be written as,

$$K(\alpha)=\frac{4}{\pi^2}\frac{1}{Bi}\int_0^{\infty}\frac{e^{-x^2 Fo}\;dx}{x\left\{\left[Bi^{\frac{1}{2}}I_0(x)+Bi^{\frac{-1}{2}}I_1(x)\right]^2+\left[Bi^{\frac{1}{2}}Y_0(x)+Bi^{\frac{-1}{2}}Y_1(x)\right]^2\right\}} \tag{3.33}$$

Replacing Bi by K/ha and x by ua in equation (3.33), it can be seen that equation (3.31) is satisfied. This provides evidence that both techniques are the same. However, Voss (1969) modified the technique so that it can be used to include calculations of the surface temperature of a wet surface and also the heat from other heat sources in the roadway.

In order to calculate the surface temperature of a wet surface, Voss (1969) replaced the air temperature v_1 by a base temperature temperature v_B, and the convective heat transfer coefficient by an effective heat transfer coefficient, h_{eff}, in equation (3.30). Thus, the wet surface temperature given by Voss (1969) is,

$$V_w(a,t)=v_B+\frac{K_{eff}}{h_{eff}}\left(\frac{v_0-v_B}{a}\right)K(h_{eff}) \tag{3.34}$$

Once the surface temperatures of both the dry and wet surface are known, the heat flux of the strata can be calculated using equations (2.5) and (2.6).

The approach shown so far, for calculating the heat from strata, was also adopted by Gibson (1976) and McPherson (1986).

The heat flowing into a roadway comes from different heat sources in the roadway. These heat emissions will consequently cause a rise in the temperature along the roadway, So far, the heat flux from strata can be evaluated. The evaluation of heat from the other heat sources is still needed in order to find the temperature increase at the end of the roadway. Voss (1969) assumed that all the heat from these heat sources is equivalent to the heat from an imaginary thickness of strata. This means further modifications of equation (3.30) and (3.33) are required in order to take account of the heat from all the heat sources in the roadway. The major modification is the replacing of the effective thermal conductivity, K_{eff}, in equation (3.30) and (3.31) by an equivalent thermal conductivity, K_{eq}. The equivalent thermal conductivity is for the heat from all the heat sources in the roadway. The thermal conductivity of strata is still used if the heat from the strata is being considered. The equivalent thermal conductivity given by Voss is,

$$K_{eq} = \frac{K_{eff}}{E_t} \tag{3.35}$$

where K_{eq} = equivalent thermal conductivity (W/m)

K_{eff} = effective thermal conductivity (W/m)

E_t = ratio of the 'dry' heat and the total heat pick-up in the roadway

3.2 TRANSIENT MODEL

A steady-state model for predicting the rate of heat and moisture transfer from the strata to the ventilation air in an underground roadway assumes that the air temperature in the roadway is either constant or that only small changes take place. This assumption is clearly not correct; air temperatures, especially those measured in underground mines by Browning et al (1977) and Schlotte (1980), displayed variations of up to 5°C at any one point during any one week. These variations are periodic in nature and relate to the production cycle operating in the mine. The heat flow from strata is therefore of a transient nature. The Duhamel Theorem is used to model the transient heat flow from strata. This method employs the single surface model.

A transient model to calculate the transient heat flux from strata in a completely dry roadway was first developed by Jordan (1961, 1965). Starfield (1966c) also applied the method to a roadway with a rectangular opening. The work by Jordan was studied by Palin (1983) at British Coal's HQTD. He extended Jordan's technique to a roadway with a partially wetted surface. Since the technique requires a lot of computation time, Palin (1983) developed a hybrid method, in which the steady-state solution is used for computing the temperature of the past history and a transient solution for the present. Burrell and Maneylaws (1985) used Palin's (1983) technique for predicting the surface temperature of a roadway, from which the heat flux from the strata can be found. At the same time, Mack and Starfield (1985) used Duhamel's Theorem to calculate the surface temperature of a roadway and to make a comparison between the surface temperature calculated using the Duhamel theorem and the method developed by Starfield and Bleloch (1983). Cheung (1989) adopted Palin's (1983) method for calculating the surface temperature of strata in a roadway. However, he did not use the hybrid method. Neverthless, in order to reduce the complexity of the computation (Cheung, 1989) still used two distinct time intervals to separate the temperature analysis in the past from that in the present (Palin, 1983) when calculating the surface temperature using the Duhamel Theorem (Carslaw and Jaeger, 1959).

3.2.1 Use of Duhamel's Theorem

The statement of Duhamel's Theorem given by Carslaw and Jaeger (1959) is that if V(a,t) represents the temperature on the surface of a hole at time, t, (the initial temperature of the solid being zero) due to a uniform unit heat flux (for unit area per unit time) flowing into the surface, then the surface temperature, ϕ(a,t), due to a time varying heat flux, f(t), is given by a convolution integral.

$$\phi(a,t) = \int_0^t f(t-\lambda)\frac{dV(a,\lambda)}{d\lambda}d\lambda \tag{3.36}$$

If the heat flux flows out of the strata which is originally at the virgin strata temperature, ϕ_0, (that is r = ∞, t = 0), rather than zero, equation (3.36) becomes,

$$\phi(a,t) = \phi_0 - f(0)V(a,t) - \int_0^t \frac{df(\lambda)}{d\lambda}V(a,t-\lambda)d\lambda \tag{3.37}$$

Equation (3.37) can be approximated, according to the Jordan's method (Jordan, 1961), by finite difference equations. Firstly, the range of the integration is divided into n intervals of δt. this gives,

$$t = n \cdot \delta t \tag{3.38}$$

Then the integral in equation (3.37) is approximated by a summation of each integral to become,

$$\phi(a,t) \approx \phi_0 V(a,t) - \sum_{s=1}^{n} \int_{(s-1)\delta t}^{s\delta t} \frac{df(\lambda)}{d\lambda} V(a,t-\lambda)\, d\lambda \tag{3.39}$$

Over each such integral, V(a, t -) is replaced by the mean of its values at the end points of the integral and removed from under the integral sign. Equation (3.39) then becomes,

$$\phi(a,t) = \phi_0 - f(0)V(a,t) - \sum_{s=1}^{n} \frac{1}{2}\{V(n\,\delta t - s\,\delta t) - V[n\,\delta t - (s-1)\,\delta t]\} \int_{(s-1)\delta t}^{s\delta t} \frac{df(\lambda)}{d\lambda} d\lambda$$

The last integral in equation (3.40) is straight forward and is equal to the difference between the limits of the integral. This gives,

$$\phi(a,t)=\phi_0-f(0)V(a,t)-\sum_{s=1}^{n}\frac{1}{2}\{V(n\,\delta t-s\,\delta t)+V[n\,\delta t-(s-1)\,\delta t]\}\{f(s\,\delta t)-f[(s-1)\,\delta t]\}$$

Equation (3.41) can be written as,

$$\phi(a,t)=\phi_0-f(0)V(a,t)-\sum_{s=1}^{n}\bar{V}_{n-s+1}\Delta_s f \tag{3.42}$$

where $\bar{V}_{n-s+1}$ = the mean of the values at the end points of the interval.

$\Delta_s f$ = the finite difference equation at the end points of the interval.

Comparisons between equation (3.41) and that given by Palin (1983), equation (2.7), shows that the summation in equation (3.41) is separated into two summations by Palin (1983); the first summation is calculated directly using the steady state solution, while the second summation is calculated using the numerical method developed by Jordan (1961).

3.2.2 The Surface Temperature Function, V(a,t)

According to the assumptions made for modelling the heat conduction process in a cylindrical roadway, the surface temperature function, V(a,t) can be found by solving the two dimensional Diffusion Equation in polar form shown below,

$$\frac{\partial^2 V}{\partial r^2}+\frac{1}{r}\frac{\partial V}{\partial r}=\frac{1}{\alpha}\frac{\partial V}{\partial t} \tag{3.43}$$

With respect to Duhamel's Theorem, the boundary conditions are, (i), the strata is initially at zero temperature, and (ii), there is a uniform unit heat flux flowing into the strata,

$$V(r,0)=0 \tag{3.44a}$$

$$-K\frac{\partial V(a,t)}{\partial r}=1 \tag{3.44b}$$

where K = the thermal conductivity of the strata (W/m)

Taking the Laplace transform of equation (3.43) in t and the boundary conditions of (2.44a) and (2.44b), the general solution of equation (3.43) obtained from sub-section 3.1.1.1 is,

$$\bar{v}(r,s)=BK_0(qr) \tag{3.45}$$

where B = constant

K_0 = Bessel function of order zero

Differentiation of equation (3.35) and substitution of the transformed boundary condition, equation (3.44b), into the differentiated equation gives,

$$\frac{d\bar{v}}{dr}=-BqK_1(qa)=\frac{-1}{Ks} \tag{3.46}$$

$$B=\frac{1}{KsqK_1(qa)} \tag{3.47}$$

Substituting B back into equation (3.46) gives,

$$\bar{v}(r,s)=\frac{K_0(qr)}{KsqK_1(qa)} \tag{3.48}$$

The inverse transform of equation (3.48) given by Carslaw and Jaeger (1959) is,

$$V(r,t)=\frac{-2}{\pi K}\int_0^{\infty}\left(1-e^{-\alpha u^2 t}\right)\left[\frac{J_0(ur)Y_1(ua)-Y_0(ur)J_1(ua)}{u^2[J_1^2(ua)+Y_1^2(ua)]}\right]du \tag{3.49}$$

The surface temperature function is obtained by substituting r = a into equation (3.49). This gives,

$$V(r,t)=\frac{-2}{\pi K}\int_0^{\infty}\left(1-e^{-\alpha u^2 t}\right)\left[\frac{J_0(ua)Y_1(ua)-Y_0(ua)J_1(ua)}{u^2[J_1^2(ua)+Y_1^2(ua)]}\right]du \tag{3.50}$$

Since $J_0(ua)\,Y_1(ua) - Y_0(ua)\,J_1(ua) = -2/\pi ua$ (Abramowitz and Stegun, 1972), equation (3.50) can be written as,

$$V(a,t)=\frac{4}{\pi^2 Ka}\int_0^{\infty}\frac{1-e^{-\alpha u^2 t}}{u^3(J_1^2(ua)+Y_{12}(ua))}du \tag{3.51}$$

Letting $Fo = \tau = \alpha t/a^2$ and $w = ua$, equation (3.51) can be written as,

$$V(a,\tau)=\frac{4a}{\pi^2 K}\int_0^{\infty}\frac{1e^{-w^2\tau}}{w^3[J_1^2(w)+Y_1^2(w)]}dw=\frac{4a}{\pi^2 K}I(\tau) \tag{3.52}$$

where $V(a, \tau)$ = the surface temperature function at dimensionless time, Fo, with unit heat flux flowing into the strata.

The integral can be approximated by two polynomials given by Jordan (1961).

For small intervals of time,

$$I(\tau) \approx 2.7842\tau^{\frac{1}{2}} - 1.2337\tau + 0.6961\tau^{\frac{3}{2}} - 0.4626\tau^{2} + 0.3654\tau^{\frac{5}{2}} - 0.3494\tau^{3} \quad (3.53)$$

For large intervals of time,

$$I(\tau) \approx \frac{1}{8}\pi^{2} \quad [\ln(4\tau) - \gamma)] \quad (3.54)$$

where γ = 0.57722, which is Euler's constant.

3.2.3 The Boundary Condition of an Imperfectly Wetted Surface

The boundary condition for an imperfectly wetted surface was given by Burrell and Maneylaws (1985). It is,

$$f(t) = [\phi(t) - \theta(t)] + \frac{\eta\beta r_{v}}{R_{d}T}\{svp[\phi(t)] - pre[\theta(t)]\} \quad (3.55)$$

where h = heat transfer coefficient at the boundary, including for completeness, the effect of radiation ($h = h_{conv} + h_{rad}$) (W/m^2),

h_{conv} = convective heat transfer coefficient, (W/m^2),

h_{rad} = radiative heat transfer coefficient, (W/m^2),

pre(θ)	=	prevailing vapour pressure at air temperature, (Pa),
svp(ϕ)	=	saturated vapour pressure at the surface temperature, (Pa),
ϕ (t)	=	surface temperature at time, t, (°C),
θ (t)	=	air temperature at time, t, (°C),
T	=	absolute surface temperature (i.e. ϕ(t) +237), (°C)
r_v	=	latent heat of evaporation, (J/kg K),
R_d	=	gas constant of water vapour, (J/kg K),
β	=	mass transfer coefficient,
Cp	=	specific heat capacity, (J/kg K),
dens	=	density of air, (kg/m^3),
η	=	wetness factor.

Simplifying equation (3.55) gives,

$$f(t) = C[\phi(t) - \Phi(t)] \tag{3.56}$$

where

$$C = C_1(h_{conv} + hrad)$$

$$C_1 = 1 + \frac{C_2 svp[\phi(t)]}{\phi(t)}$$

$$C_2 = \frac{C_3 h_{conv} \eta}{h_{conv} + h_{rad}}$$

$$C_3 = \frac{r_v}{R_d T Cp\, dens}$$

$$\Phi(t) = \frac{\theta(t) - C_2 pre[\theta(t)]}{C_1}$$

3.2.4 The Rate of Heat Transfer in A Wetted Airway

Since the function for the surface temperature of a cylinder (section 3.2.2) and the varying heat flux function, f(t) (section 3.2.3) of a wetted roadway are obtained, the surface temperature of a wetted roadway can be calculated from equation (3.40). Substituting equations (3.51) and (3.55) into equation (3.41) gives,

$$\phi(a,n)=\phi_0-C[\phi(0)-\Phi(0)]\cdot\frac{4a}{\pi^2}I(\tau)-\frac{4a}{\pi^2K}\sum_{s=1}^{n}\frac{1}{2}(I_{n-s}-I_{n-s-1})[f(s\delta t)-f(s-1)\delta t]$$

where $$\frac{1}{2}(I_{n-s}+I_{n-s+1})=\frac{1}{2}\{I[n\delta t-(s-1)\delta t])\} \tag{3.58}$$

If n=1, the surface temperature at the first interval is,

$$\phi(a,1)=\phi_0-C[\phi(0)-\Phi(0)]\cdot\frac{4a}{\pi^2K}I_1-\frac{4a}{\pi^2K}\frac{1}{2}(I_0-I_1)\{C_1[\phi(1)-\Phi(1)]-C_0[\phi(0)-\Phi(0)]\} \tag{3.59}$$

As I_1, I_0, $\Phi(0)$ and $\Phi(1)$ are known, and the surface temperature at the first interval, $\phi(a,1)$, can be found, $\phi(a,2)$ can be solved. Thus the series $\phi(a,n)$ can be built up.

Once the surface temperature $\phi(a,t)$ of the wetted roadway is defined, the "dry" and "wet" heat flux can be calculated. The total heat flux is simply $C[\phi(t)-\Phi(t)]$ and the dry heat flux is $h_{conv}[\phi(t)-TD]$ where TD is the dry bulb temperature of the prevailing air in the roadway. The wet heat heat flux can be obtained by a simple subtraction of the dry heat flux from the total heat flux.

3.2.5 Algorithm for the Computation of An Increase in Air Temperature

An iterative technique is used to calculate an increase in the air temperature along an underground roadway. The following steps are taken :

(i), The airway is divided into small lengths.

(ii), The surface temperature at the inlet of the sectioned airway is calculated according to equation (3.41) which itself requires the use of iteration. The heat flux function, f(t), is calculated using equation (3.55) for which the surface temperature is assumed in order to start the iteration. The initial assumption will either be the strata temperature if it is higher than the dry bulb temperature of the ventilation air which is already known, or the dry bulb temperature of the air if it is higher than the strata temperature. The surface temperature function is then calculated according to the equation (3.51). The time in equation (3.51) is stepped at two rates in order to reduce the number of time intervals: for distant history, t is given as,

$$t = \frac{\text{age of roadway}}{40} \quad ,$$

and a two hours interval is assumed for the most recent history which is taken as being during the production week under consideration. A conditioning week with a 2 hour interval is added before the week under consideration for a smooth transition between the two periods (i.e. distant and recent history). The iteration stops when the surface temperature calculated from equation (3.41) agrees with the assumed value.

(iii) The heat flux is calculated and it is separated into dry and wet heat flux.

(iv) Initially a constant heat flux flowing between the strata and air over the sectioned roadway is assumed so that the air temperature at the end of this section can be predicted.

(v) With the predicted air temperature, it is possible to calculate the heat flux flowing at the end of the sectioned roadway as in steps (ii), (iii) and (iv).

(vi) An average heat flux is taken between both ends of this section which provides a new set of predictions of the air temperature at the end of the sectioned roadway.

(vii) If the new set of predicted temperatures are within 0.15 °C of the temperature predicted previously, the newly predicted temperature will be used as the input temperature for the next section of the roadway. Otherwise, the new set of predictions are used to re-calculate the surface temperature as in (ii) and the heat flux as in (iii) and (iv). Subsequently, the average heat flux flowing between the strata and the air is found. This will provide new predictions.

CHAPTER FOUR

MISCELLANEOUS HEAT SOURCES

Climatic investigations undertaken by Browning et al (1977, 1980) (Figure 2.1), Whittaker (1979), and Browning (1980) showed that, although the heat emission of strata accounts for 70 - 80 % of the total heat emission in a longwall mining district, the heat emission of the strata, during a peak production period, is small compared to the heat emitted by cut coal (inclusive of the cut coal on a conveyor) and by machinery. Moreover, the difference between the heat pick-up by the ventilation air and the total heat emission during a five hour production shift provides evidence for a considerable degree of heat storage in strata and/or steelwork. It can also be seen from Figure 2.1 that during a five hour production shift, the heat emission of cut coal may approach 50 % (205s) , and the heat emitted by machinery may also approach 50 % (65s and T1s), of the total heat emission. This indicates that the heat emitted by the conveyed coal and by the machinery can have a significant effect on the air temperature. However, at high strata temperature (204s), the heat contribution from machinery reduces to 25 % because of an increase in the strata heat. In addition, the heat stored in the strata and/or steelwork is upto 150 - 350 KW during a peak activity period. This value can be obtained from the difference between the heat pick-up and the heat emission during a five hour production shift.

Schlotte (1980) investigated heat emissions from conveyed coal, strata and machinery in German coalmines. The conclusions made from Schlotte's investigations (1987) are,

(i) The demand for a higher coal output will increase the heat transfer between the conveyed coal and the ventilation air. The heat will flow from conveyed coal to ventilation air when the coal temperature is higher than the ventilation air, and vice versa.

(ii) Higher coal output increases the power consumed by machinery.

When the coal temperature is lower than the air temperature the coal will absorb heat from the ventilation air which is subsequently cooled as it travels inbye to a working district. The heat absorbed by the conveyed coal will then be released to cooler parts of the district as the coal travels outbye.

So far, it can be concluded that the heat emission in a longwall mining district, during a peak production period, is mainly from the cut coal and machinery. Apart from heat emissions in the district, the heat balance during a peak production period shows that there is a considerable degree of heat storage in conveyed coal, roadway strata and the steelwork, as the air temperature is raised due to the heat from machinery.

4.1 HEAT FROM CONVEYED COAL

A theoretical method to calculate heat flow from conveyed coal was first given by Voss (1965). He assumed that the cut coal on a continuous conveyor could be modelled as a continuous slab of uniform thickness. The method used to calculate the heat flow from a continuous slab is based on the Schmidt method (Cornwell, 1980) which is basically a finite difference method. The advantage of this method is that calculations can be carried out manually. The calculation begins by dividing the slab into several parallel slabs of equal thickness. It is assumed that the air temperature is known. The temperature at the bottom of the conveyor belt can then be calculated. Thus, the temperature of each individual slab can be found using the Schmidt method (Cornwell, 1980). It is not possible to begin the calculation at the top surface of the slab because the coal surface is constantly wetted by dust supression water, and the

Schmidt method cannot be applied to a wet surface, where mass transfer (evaporation or condensation of moisture) is taking place.

Gracie and Matthew (1976) pointed out that the heat from conveyed coal has a significant influence on the temperature of ventilation air in a roadway. They also suggested that it is important to take account of the heat from conveyed coal in any mine climate calculations for conveyor roadways.

A computer programme was developed by Hermanns (1976) to calculate the heat from conveyed coal. This programme is based on the theoretical method developed by Voss (1965).

A full scale experimental rig was built by Watson (1982) to model heat flow from the coal on a conveyor. He carried out tests on the thermal properties of conveyed coal. These tests relate the heat transfer coefficient and thermal conductivity of coal, for different moisture contents, and for different air velocities flowing over the coal on the conveyor. From his experiments, Watson (1982) produced an empirical equation to show the relationship between the heat transfer coefficient and the air velocity. The empirical equation given by Watson (1982) is,

$$h_c = 0.25u^{0.7} \tag{4.1}$$

where h_c = heat transfer coefficient (W/m^2)

u = air velocity (m/s)

The thermal conductivities obtained from Watson's (1982) laboratory tests on dry coal, dry run-of-mine (ROM) coal and ROM coal with 5 % moisture content, are 0.102 W/m°C, 0.118 W/m°C and 0.156 W/m°C, respectively. These results show that the coal with 5 % moisture content has the highest thermal conductivity. Watson (1982) also carried out experimental work at Pye Colliery, England, where he investigated the heat flow from conveyed coal in a conveyor roadway. The conclusion of his site investigation was that it is difficult to obtain resonably accurate measurements in order to evaluate the heat emitted from the conveyed coal, due to the fact that there are too many variables affecting the readings made at the site. These variables include the temperature and humidity of ventilation air, the air velocity and the conveyor speed.

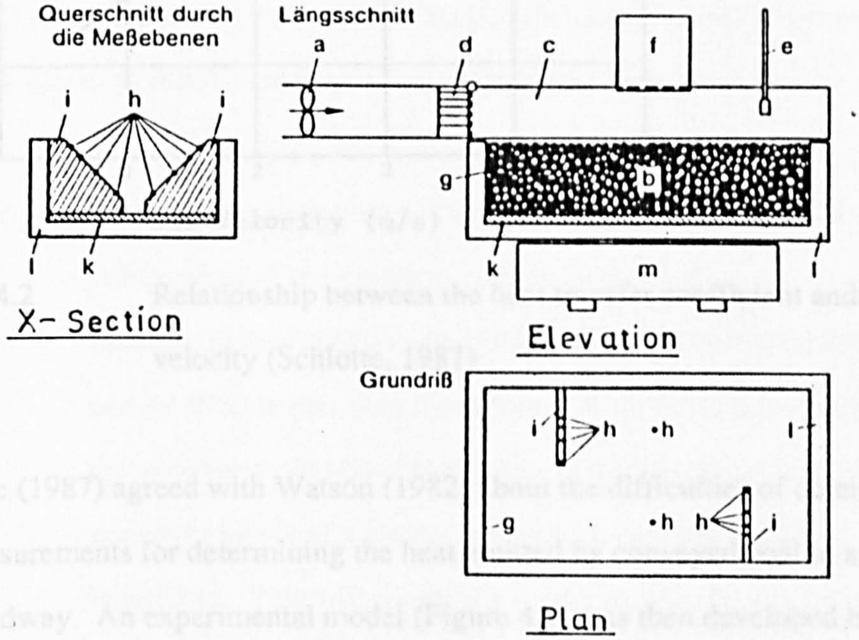


Figure 4.1 Simplified Representation of the arrangement of the equipment for Schlotte's experiment (Schlotte, 1987)

where	a	= controllable electric fan	i	=	mounting for the thermo-couple
	b	= broken coal			
	c	= hood on swivel	k	=	heating plate
	d	= rectifier	l	=	polystyrene
	e	= hot wire anemometer	m	=	electronic scale
	f	= infra-red temperature gauge	n	=	cross section through the measuring planes
	g	= container	o	=	longitudinal section
	h	= thermocouple	p	=	ground fan

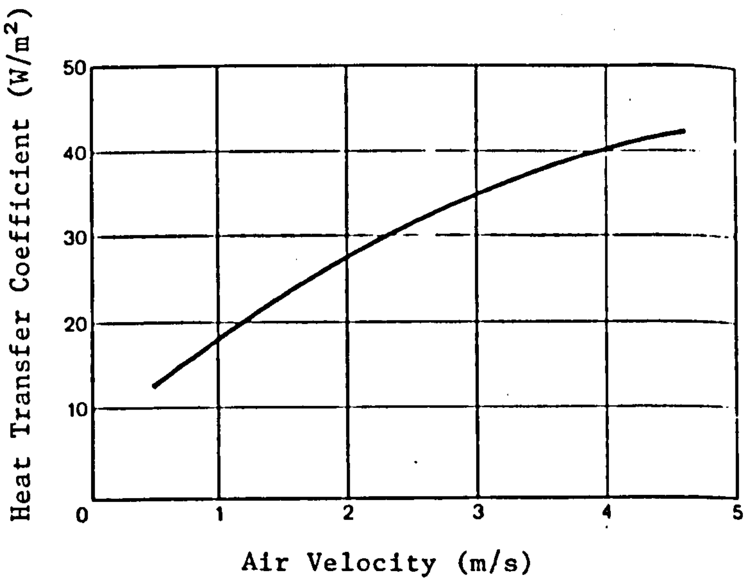


Figure 4.2 Relationship between the heat transfer coefficient and air velocity (Schlotte, 1987)

Schlotte (1987) agreed with Watson (1982) about the difficulties of obtaining accurate measurements for determining the heat emitted by conveyed coal in a conveyor roadway. An experimental model (Figure 4.1) was then developed by Schlotte (1987). Using this model, he carried out comprehensive tests on the heat transfer from air flowing over a slab of coal. The experiments were only concerned with the surface temperature of coal because the rate of heat flow between the conveyed coal and the ventilation air is proportional to the difference between the coal surface temperature and the air temperature over the coal. Heat flow through the conveyor belt is assumed to be negligible. Experiments were conducted in an air-conditioned room, in which the temperature of the room was between 30 °C and 35 °C, with relative humidities between 40 to 70 %, respectively. From the experiments, the heat transfer coefficient, and the equivalent thermal conductivity, of coal samples were obtained. The heat transfer coefficient was related to the air velocity over the coal sample (Figure 4.2). A comparison between the heat transfer coefficients obtained from Schlotte's experiment (1987) and that obtained from

Watson's (1982) empirical equation shows that Schlotte's (1987) values are higher than those of Watson (1982). This may be because the coal samples used in Schlotte's (1987) experiment, has a higher moisture content than those used by Watson (1982). Similarly, the thermal conductivities found by Schlotte (1987) are higher than those found by Watson (1982). The thermal conductivity given by Schlotte (1987) are between 0.16 and 0.28 W/m K. The conclusions, which may be drawn from Schlotte's (1987) experiment include the following.

(i) The rate of evaporation of moisture from a coal surface is independent of the moisture content of the coal.

(ii) The heat transfer coefficient obtained from in-situ measurement can be 60 % higher than those found in the laboratory because of the variable grain size distributions of conveyed coal. Also the conveyor belt is of a greater length than that used in the laboratory. This will result in a higher Reynold's number and thus a higher heat transfer coefficient for the conveyed coal.

(iii) The heat transfer between the ventilation air and the conveyed coal is of a transient nature, in that "dry" heat can be absorbed by the conveyed coal and that gain used to increase the rate of evaporation of moisture, because the coal temperature is lower than the dry bulb temperature but higher than the wet bulb temperature, of the ventilation air. If the coal temperature is lower than both the dry and wet bulb temperature of the ventilation air, condensation can occur on the coal surface. This means that the ventilation air would be cooled by the conveyed coal, and the heat gained by the coal from the ventilation air would be released to some cooler parts of the mine.

4.1.1 Transient Heat Flow

It can be concluded from investigations of heat flow from conveyed coal that the heat transfer between the ventilation air and the conveyed coal is of a transient nature. Hence, the heat conduction process occurring in the conveyed coal is best modelled by transient analysis (Cheung and Rabia, 1989). Duhamel's Theorem is therefore used. The Duhamel Theorem has been described in section 3.2.1 for use in modelling the transient heat flow from the strata in a roadway.

The Duhamel Theorem is used to calculate the surface temperature of the conveyed coal on a continuous conveyor belt. The heat flux function is the same as that for the strata (section 3.2.3) because of a partially wetted coal surface. The temperature function is different from that of the strata since heat flow from strata and heat flow from conveyed coal are physically different from each other. In the first case, heat conduction is in a circular cylinder, and in the second case heat conduction is in a parallel slab.

In order to model the heat flow from conveyed coal on a continuous conveyor, the following assumptions are made:

(i), the coal on a continuous conveyor belt is assumed to be a continuous slab,

and (ii), the heat flow through the conveyor belt is negligible.

The model produces the surface temperature of the coal only and does not deal with the body temperature as described in the graphical technique developed by Voss (1969) and applied by Hermanns (1976).

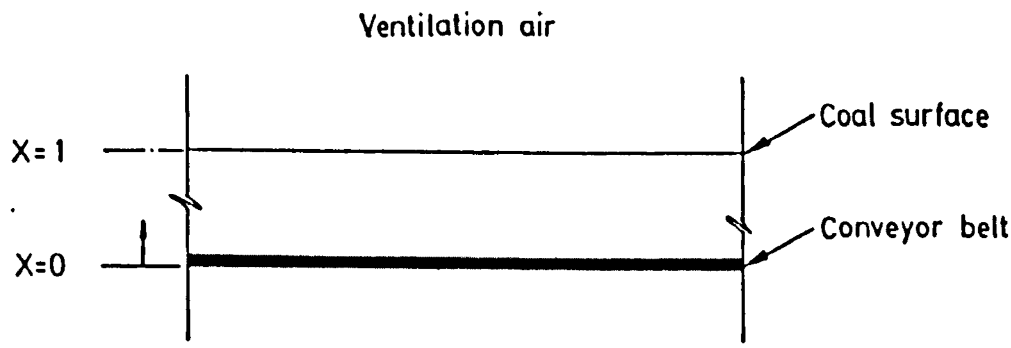


Figure 4.3 The Geometry of Conveyed Coal on a Continuous Conveyor Belt.

4.1.1.1 Use of Duhamel Theorem

Figure 4.3 shows the geometry of the conveyed coal on a continuous conveyor belt. The coal is assumed to be a paralell slab with a thickness of l. It is measured from the surface of the belt where x = 0 to the surface of the conveyed coal, where x = l.

The Duhamel Theorem is applied to this problem assuming that if V(l,t) represents the surface temperature of a parallel slab at time t (the initial temperature of the slab being zero), due to uniform unit heat flux flowing into the surface, then the surface temperature ϕ(l,t) due to a time varying heat flux f(t), is given by a convolution integral in a dummy variable λ.

$$\phi(l,t) = \int_0^t f(t-\lambda)\frac{dV(l,\lambda)}{d\lambda} \tag{4.2}$$

If the heat flux flows out of the slab which is initially at a constant temperature ϕ_o, rather than zero, then equation (4.2) becomes,

$$\phi(l,t) = \phi_0 - \int_0^t f(t-\lambda)\frac{dV(l,\lambda)}{d\lambda}\,d\lambda \tag{4.3}$$

Integrating equation (4.3) by parts yields,

$$\phi(l,t) = \phi_0 - f(0)V(l,t) - \int_0^t \frac{df(\lambda)}{d\lambda}V(t-\lambda)\quad d\lambda \tag{4.4}$$

Approximation of equation (4.4) by the Jordan's Numerical Method (section 3.2.1)gives,

$$\phi(l,n) = \phi_0 - f(0)V(l,n) - \sum_{s=1}^{n} \bar{V}_{n-s+1}\Delta_s f \tag{4.5}$$

where $\bar{V}_{n-s+1}$ = the mean of the values at the end points of the sub interval.

$\Delta_s f$ = the finite difference between the limit of the integral.

4.1.1.2 Temperature function of a parallel slab, V(l,t)

The heat conduction process occurring in a continuous slab can be described by a one dimensional heat diffusion equation using cartesian coordinates, as shown below,

$$\frac{\partial^2 V}{\partial x^2} = \frac{1}{\alpha}\frac{\partial V}{\partial t} \tag{4.6}$$

The boundary conditions for the Duhamel theorem are, (i), the conveyed coal is initially at zero temperature, and (ii), there is a uniform unit heat flux flowing into the coal surface,

$$V(x,0) = 0 \tag{4.7a}$$

$$\frac{\partial V(0,t)}{\partial x} = 0 \tag{4.7b}$$

$$\frac{\partial V(l,t)}{\partial x} = \frac{1}{K} \tag{4.7c}$$

where K = thermal conductivity of conveyed coal

Taking the Laplace Transform of equations (4.6), (4.7b) and (4.7c) in t gives,

$$\frac{d^2\overline{v}}{dx^2} = \frac{1}{\alpha} s\overline{v} \tag{4.8}$$

$$\frac{d\overline{v}(0,s)}{dx} = 0 \tag{4.9}$$

$$\frac{d\overline{v}(l,s)}{dx} = \frac{1}{Ks} \tag{4.10}$$

where $\overline{v}(x,s) =$ the Laplace Transform of $V(x,t)$

The general solution of equation (4.8) is,

$$\bar{v}(x,s) = A\cosh\left(\sqrt{\frac{s}{\alpha}}x\right) + B\sinh\left(\sqrt{\frac{s}{\alpha}}x\right) \tag{4.11}$$

where A and B are constants.

Substitution of the transformed boundary conditions, equations (4.9) and (4.10), into equation (4.11) gives,

$$A = \frac{\sqrt{\alpha}}{K}\frac{1}{s^{\frac{3}{2}}\sinh\left(\sqrt{\frac{s}{\alpha}}l\right)} \tag{4.12a}$$

$$B = 0 \tag{4.12b}$$

The exact solution of equation (4.8) then becomes,

$$\bar{v}(x,s) = \sqrt{\frac{\alpha}{K}}\frac{\cosh\left(\sqrt{\frac{s}{\alpha}}x\right)}{s^{\frac{3}{2}}\sinh\left(\sqrt{\frac{s}{\alpha}}l\right)} \tag{4.13}$$

The inverse transform of equation (4.13) can be found by using the Inverse Integral Theorem due to Spiegel (1987). This gives,

$$V(x,t) = \sqrt{\frac{\alpha}{K}}\frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty}\frac{\cosh\left(\sqrt{\frac{s}{\alpha}}x\right)}{s^{\frac{3}{2}}\sinh\left(\sqrt{\frac{s}{\alpha}}l\right)}\quad e^{st}dt \tag{4.14}$$

The apparent branch point at s = 0 is fictitious as expanding the hyperbolic in power series shows them to be purely functions of s and not of √s.

There is a pole of order 2 at s = 0 and simple poles at,

$$\sqrt{\frac{s}{\alpha}}\,l = in\pi \tag{4.15}$$

that is at,

$$s = \frac{-\alpha n^2\pi^2}{l^2} \tag{4.16}$$

To calculate the residue at s = 0, the integrand in equation (4.14) is expanded about s=0,

$$I = \frac{(1+\frac{1}{2}\frac{s}{\alpha}x^2+\ldots)(1+st+\ldots)}{s^{\frac{3}{2}}\left[\sqrt{\frac{s}{\alpha}}\,l+\frac{1}{6}(\frac{s}{\alpha})^{\frac{3}{2}}l^2+\ldots\right]} \tag{4.17}$$

$$I = \frac{1}{s^2}\frac{\sqrt{\alpha}}{l}\left[1+s\left(t+\frac{x^2}{2\alpha}\right)+\ldots\right]\left[1-\frac{1}{6}\frac{s}{\alpha}l+\ldots\right] \tag{4.18}$$

$$I = \frac{1}{s^2}\frac{\sqrt{\alpha}}{l}\left[1+s\left(t+\frac{x^2}{2\alpha}-\frac{1}{6\alpha}\right)+\ldots\right] \tag{4.19}$$

Hence, the residue is,

$$\lim s \to 0 \qquad s\left[\frac{1}{s^2}\frac{\sqrt{\alpha}}{l}\left[1+s\left(t+\frac{x^2}{2\alpha}-\frac{l}{6\alpha}\right)+\ldots\right]\right] \tag{4.20}$$

$$=\frac{\sqrt{\alpha}}{l}\left(t+\frac{x^2}{2\alpha}-\frac{l}{6\alpha}\right) \tag{4.21}$$

To calculate the residue at,

$$s=e^{i\pi}\frac{\alpha n^2\pi^2}{l^2}$$

let, $s=e^{i\pi}\dfrac{\alpha n^2\pi^2}{l^2}+\varepsilon$

The coefficient of ϵ^{-1} is included in the expansion of the integrand in equation (4.14). This gives,

$$\lim \varepsilon \to 0 \qquad \varepsilon\left[\frac{\cosh\left(\sqrt{\frac{s}{\alpha}}x\right)\cdot e^{st}}{s^{\frac{3}{2}}\sinh\left(\sqrt{\frac{s}{\alpha}}l\right)}\right] \tag{4.22a}$$

$$=\lim \varepsilon \to 0 \qquad \varepsilon\left\{\frac{\cosh\left[\frac{in\pi}{l}\left(1-\frac{1}{2}\frac{\varepsilon l^2}{\alpha n^2\pi^2}+\ldots\right)x\right]\cdot e^{\frac{-\alpha n^2\pi^2}{l^2}t}}{\left[e^{i\frac{3\pi}{2}}\left(\frac{\alpha n^2\pi^2}{l^2}\right)^{\frac{3}{2}}+\ldots\right]\sinh\left[in\pi\left(1-\frac{1}{2}\frac{\varepsilon l^2}{\alpha n^2\pi^2}+\ldots\right)\right]}\right\} \tag{4.22b}$$

$$= \lim \varepsilon \to 0 \qquad \varepsilon \left\{ \frac{\cos(\frac{n\pi x}{l}) \cdot e^{\frac{-\alpha n^2 \pi^2}{l^2} t}}{-i\alpha^{\frac{3}{2}} \frac{n^3 \pi^3}{l^3} i \cos(n\pi) \cdot (-1) \frac{1}{2} \frac{\varepsilon l^2}{\alpha n^2 \pi^2} n\pi} \right\} \tag{4.23}$$

$$= \frac{-2l}{\sqrt{\alpha}\, n^2 \pi 2} (-1)^n \cos\left(\frac{n\pi x}{l}\right) \cdot e^{\frac{-\alpha n^2 \pi^2 t}{l^2}} \tag{4.24}$$

Therefore, the temperature function is,

$$V(x,t) = \frac{\sqrt{\alpha}}{K} \left\{ \frac{\sqrt{\alpha}}{l} \left(t - \frac{x^2}{2x} - \frac{l}{6\alpha} \right) + \sum_{n=1}^{\infty} \frac{-2l(-1)^n \cos(\frac{n\pi x}{l})\, e^{\frac{-\alpha n^2 \pi^2 t}{l^2}}}{\sqrt{\alpha}\, n^2 \pi^2} \right\} \tag{4.25}$$

Simplifying equation (4.25) gives,

$$V(x,t) = \frac{\alpha t}{Kl} + \frac{1}{2} \frac{x^2}{Kl} - \frac{l}{6K} - \frac{2l}{K\pi^2} \sum_{n=1}^{\infty} \frac{(-1)^n}{n^2} e^{\frac{-\alpha n^2 \pi^2 t}{l^2}} \cos\left(\frac{n\pi x}{l}\right) \tag{4.26}$$

Subtituting x = l into equation (4.26) gives,

$$V(l,t) = \frac{-\alpha t}{Kl} - \frac{l}{3K} + \frac{2l}{K\pi^2} \sum_{n=1}^{\infty} \frac{(-1)^n}{n^2} e^{\frac{-n^2 \pi^2 t}{l^2}} \cos(n\pi) \tag{4.27}$$

4.1.1.3 Algorithm for computation of the surface temperature

The algorithm proceeds as follows,

(i), Initialize the input data. The air temperatures over the conveyed coal are assumed to vary linearly.

(ii), Calculate the thickness of the conveyed coal, the relative velocity between the air and the belt, and the heat transfer coefficient, using the equations described by Hermanns (1976). These equations are as follows:

the thickness of the conveyed coal is given by,

$$s = \frac{M_k}{\rho_s W_B b 3600}$$

where	s	=	thickness of coal (m),
	M_k	=	haulage rate (kg/h),
	W_B	=	speed of conveyor (m/s),
	b	=	conveyor width (m)
	ρ_s	=	density of coal (kg/m³).

the heat transfer coefficient is given by,

$$h_c = 3.93 w^{0.79} (1 + 36 K_s^{0.79})$$

where	h_c	=	heat transfer coefficient (W/m$_2$),
	w	=	relative speed (m/s),
	K_s	=	average height of surface irregularitity (m).

(iii), Divide the roadway into small lengths and assumed ten intervals in every divided length of roadway.

(iv), Calculate the time interval (δt) for each sub-divided length,

$$\delta t = \frac{\text{length of roadway}}{\text{total number of divided lengths} \times w}$$

(v), Calculate the temperature function, V(l,t), at each time interval.

(vi), Calculate the surface temperature at the first interval. This will require iterations, in that the surface temperature is initially assumed in order to obtain the heat flux at the first interval, f(1). It is then substituted, together with the temperature function at the first interval, and the heat flux and temperature function at time equal to zero, into equation (4.5). Equation (4.5) then gives the surface temperature, which is compared with the assumed temperature. If the surface temperature does not agree with the assumed temperature, further assumptions are made. The iteration stops when the calculated surface temperature agrees with the assumed temperature.

(vii), The calculation of the surface temperature is continued for the next time interval and so on until the surface temperature at the last time interval is found.

4.2 MACHINERY HEAT

The machinery used in underground mines is powered by electricity, diesel fuel or compressed air. The major heat contribution from machinery is from that powered by electricity (Browning at al, 1977), because all electrical energy is either converted to heat energy or useful work. The heat from machinery powered by diesel fuel and compressed air is usually insignificant compared to the total heat emission in a mine (Oakes and Hinsley, 1955).

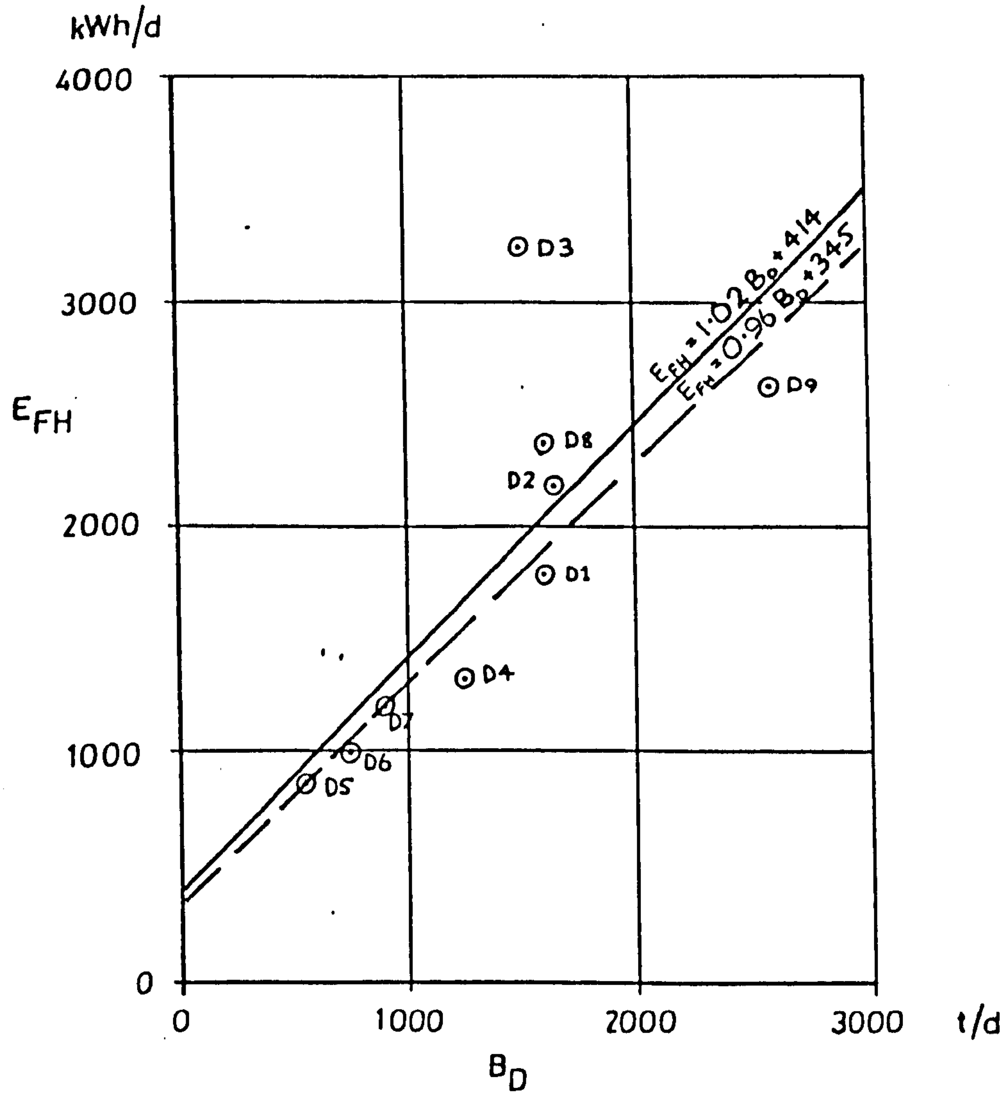


Figure 4.4 Electrical Energy as Heat, E_{FH}, for Faces Compared with Daily Output, B_D, (Browning and Burrell, 1980)

The machinery installed at a longwall district, is mainly for coal production. It includes the shearer for coal cutting, and the conveyor system for transporting the coal outbye from the coal production area. The electrical power consumed by this machinery depends on the rate of coal production. The heat emitted by the machinery is, therefore, related to the power consumed by the machinery, and so its rate of heat emission is related to the production shift. For the shearer, some electrical power will produce useful work, that is to cut coal, and some will be converted to heat, which increases the coal temperature due to frictional heat, and the ambient temperature. For the conveyor system, some electrical power will be used to transport coal to the surface, and some will be converted to heat due to the inefficiency of the motor and the friction between the moving parts in the conveyor system.

Since there are many uncertainties about the rate of heat emission from machinery, Browning et al (1977) concluded that it would be difficult to model the heat from machinery theoretically, and proposed that an empirical method be used for estimating the heat emitted by the machinery. Investigations of the power consumption of electrical machinery were carried out by Browning et al (1977) in a number of longwall mining districts. The power consumed by the machinery was plotted against the coal production. A linear regression analysis was used to produce an empirical equation for the estimation of the heat emitted from the machinery. Figure 4.4 shows an empirical equation for electrical energy emitted as heat, E_{FH}, from faces related to the daily output, B_D, (Browning and Burrell, 1980). An empirical equation is also given by Browning et al (1982) for the electrical power appearing as heat from faces. This equation is shown below,

$$P_{FH} = \frac{1}{t_R}(1.26B_D + 1.66) \qquad (4.28)$$

where P_{FH} = power appearing as heat (KW)

B_D = run-of-mine output (t/day)

t_R = total running time (hours)

A semi empirical equation was developed by Browning et al (1982) for the heat emitted by conveyor machinery. They considered the total mechanical power required by the conveyor (Pt) to have three components: (i), the power to drive the empty belt (Pe), (ii), the power to move the load horizontally (Pl), and (iii), the power to raise or lower the load (Pg). Allowing for the efficiency of motor and gearing, an empirical equation for the power appearing as heat, which is the power applied less that used to overcome gravity, for conveyor machinery was given by Browning (1982). This equation is shown below,

$$P_{CH} = \frac{1}{\tau}(Pe + Pl + Pg) - Pg \qquad (4.29)$$

Equation (4.29) can also be written as,

$$P_{CH} = \frac{9.81}{\tau}\left(fswL + MfL + \frac{(1-\tau)Mh}{1000}\right) \qquad (4.30)$$

where

f	=	the coefficient of friction
w	=	the mass per unit length of moving parts (belts and roller) (kg/m)
s	=	the conveyor speed (m/s)
L	=	the conveyor length (km)
h	=	the height of lift (negative for a fall) (m)
M	=	the conveyor load (kg/s)
τ	=	the motor and gearing efficiency

Equation (4.30) can further be approximated by substituting into it some typical values for, the coefficient of friction, f = 0.019, the mass of moving parts, w = 44.8 kg/m, and the conveyor speed, s = 1.9 m/s. Equation (4.30) then becomes,

$$P_{CH} = 19.34L\left(1 + 0.00327\frac{B_D}{t_R}\right) \tag{4.31}$$

The length, L, in equation (4.31) is not the actual length of the conveyor belt. For the conveyor belt in maingates, L = actual length + 0.4 km, and for the trunk conveyor, 0.3 km is added instead of 0.4 km.

In addition to the semi-empirical equation for the heat emitted by machinery, a purely empirical expression is also given by Browning et al (1982) which is shown below,

$$P_{CH} = \frac{1}{t_R}(0.173B_D L + 77) \tag{4.32}$$

4.3 HEAT STORAGE IN STRUCTURAL STEEL

Heat emissions from conveyed coal and machinery during production shifts in a gateroad can cause an increase in the ventilation air temperature. Some of the heat gained by the ventilation air will be lost to heat the structural steel in the gateroad. As the air temperature decreases after production stops, the heat stored in the steel will then be released back to the ventilation air. Hence, the steelwork can either be a heat sink or a heat source in the gateroad, and its effect is to dampen fluctuations in the air temperature.

Gracie and Matthew (1975) investigated the effect of heat storage in structural steel. They suggested that the heat stored in structural steel weighing 1000 tonnes could be up to 280 KW for an increase in steel temperature of 1 °C in half an hour.

Vost (1978) attempted a theoretical explanation for the effect of heat storage in steel arches in a gateroad. He suggested that Gracie and Matthew (1975) had over-estimated the amount of heat stored in steel, and by using the Lump capacity method (Incropera and De Witt, 1981), Vost (1978) showed that it would take 9 hours for the steel to gain 63 % of the air temperature rise and 20 hours to gain 90 %.

Both of above considerations by Gracie and Matthew (1975) and Vost (1979) on the effect of heat storage in steel seem to be speculative, as the steelwork in a gateroad is takes many complex shapes and the heat transfer processes taking place must be very complex. In order to make an attempt to model the heat transfer between the steel and the air, certain assumptions are therefore necessary.

The technique used to model the heat transfer between the steel and the air assumes that the steel work is a lumped mass which is considered to have a single average temperature. An average heat transfer coeffcient is then used. The surface of the steel is also assumed to be partially wetted.

4.3.1 Transient Heat Flow From the Steelwork

The first law of thermodynamics when applied to the heat flow from steelwork is as follows,

$$\text{heat out of steel} = \text{decrease of internal energy of steel} \tag{4.33}$$

Considering the left hand side of equation (4.33), the heat flux from the steel to the air is given by equation (4.34).

$$Q_s = H_s(T - \text{Theta}) \tag{4.34}$$

where H_s & Theta = functions of the dry bulb temperature, wet bulb temperature, the heat transfer coefficient, h_s, and the wetness factor, η

T = air temperature (°C)

It should be noted that equation (4.34) is the same as the heat flux function for a partially wetted surface shown in equation (3.55).

Equation (4.34) can be written as,

$$H_s A_s [T(t) - T_\infty] = M_s C_s \frac{dT}{dt} \tag{4.35}$$

where A_s = surface area of steel (m^2)

$T(t)$ = steel temperature at time t (°C)

T_∞ = air temperature (°C)

M_s = mass of steel (kg)

C_s = specific capacity of steel (J/kg K)

Putting $K = (Hs\ As)/(Ms\ Cs)$, and integrating equation (4.35) gives,

$$T(t) = T_\infty + B e^{-Kt} \tag{4.36}$$

where B = the constant of integration.

If $T = T_0$ when $t = t_0$, then B can be found, and equation (4.36) becomes,

$$T(t) = T_\infty + (T_0 - T_\infty)e^{-K(t-t_0)} \tag{4.37}$$

If the temperature of the steel is T_f at $t = t_0 + dt$, then equation (4.37) becomes,

$$T_f = T_\infty + (T_0 - T_\infty)e^{-K dt} \tag{4.38}$$

The average rate of total heat flow, Q_{stot}, from the steel to the air during the interval (t_0, $t_0 + dt$) is given by,

$$Q_{stot} = \frac{1}{dt}\int_{t_0}^{t_0+dt} H_s A_s (T - T_\infty) dt \tag{4.39}$$

Integration of equation (4.39) gives,

$$Q_{stot} = \frac{M_s C_s}{dt}(T_0 - t_\infty)(1 - e^{-K dt}) \tag{4.40}$$

The average rate of "wet" heat flow , Q_{swet} from the steel to the air during the interval (t_0, $t_0 + dt$) is given by the total heat flow rate minus the dry heat flow rate. That is,

$$Q_{swet} = Q_{stot} - \frac{1}{dt}\int_{t_0}^{t_0+dt} h_s A_s (T - TD)\, dt \tag{4.41}$$

where TD = the dry bulb temperature of air.

Integration of equation (4.41) gives,

$$Q_{swet} = \frac{(H_s - h_s)}{H_s} Q_{stot} + h_s A_s (TD - T_\infty) \qquad (4.42)$$

Thus, the total heat flux and the wet heat flux can be found by equations (4.40) and (4.42).

CHAPTER FIVE

PSYCHROMETRY

Heat emitted by strata, conveyed coal and machinery, and moisture from the latent heat of evaporation, flowing into an underground roadway, are picked-up by the ventilation air in order to maintain an acceptable working environment. The amount of heat and moisture which can be absorbed depends on the quality of air. This is determined by the psychrometric property of the air.

The psychrometric property of air can be determined by a psychrometric chart, a steam table and empirical equations. The advantage of using a psychrometric chart is that the psychrometric process (i.e. heating, cooling and humidification of air) can be plotted on the chart. The steam table can be used to calculate the psychometric state of the air as the water vapour in the air is treated as steam at low vapour pressure. The table allows manual calculations to be carried out. The empirical equations are very useful as they can be easily programmed into a computer. A full derivation of the empirical equation can be found in the literature (Gibson, 1976; Anon, 1979).

The psychrometric state of air can be measured by a psychrometer. The psychrometers, which are currently used for mine ventilation practice, are the Sling Psychrometer, the Assman Psychrometer and the Thermohygrograph. Both Sling and Assman Psychrometers measure the dry bulb and wet bulb temperatures of air. The Thermohygrograph continuously measures the dry bulb temperature and the humidity of the air.

5.1 PSYCHROMETRIC EQUATIONS

The following equations for calculating of the psychrometric state of air are given by Jones and Browning (1974):

(1), for actual vapour pressure (Pa),

$$e = e_w - 6.66 \times 10^{-4} P (t - t_w) \tag{5.1}$$

(2), for mixing ratio (kg/kg),

$$r = 0.622 \frac{e}{P - e} \tag{5.2}$$

(3), for relative humidity (%),

$$u = 100 \frac{e}{e_d} \tag{5.3}$$

(4), for density (kg/m³),

$$\rho = \frac{3.48(P - 0.378e)}{1000(273 + t)} \tag{5.4}$$

(5), for enthalpy (kJ/kg),

$$h = 4.187t(0.24 + 0.45r) + 2500r \tag{5.5}$$

where e_w = the saturation pressure at wet bulb temperature (Pa)

P = the total atmospheric pressure (Pa)

t = the dry bulb temperature (°C)

t_w = the wet bulb temperature (°C) .

e_d = the saturation vapour pressure at dry bulb temperature (Pa)

5.2 APPLICATIONS OF PSYCHROMETRIC EQUATIONS

The psychrometric equations can be used to calculate an increase in the air temperature in an underground roadway providing the heat flowing into the roadway is known. If the total heat flowing into the roadway is Q (kJ) and the dry bulb and the wet bulb temperatures at the inlet are T_{d1} and T_{w1}, respectively (the subscript 1 relates to the inlet of the roadway), the dry bulb and the wet bulb temperature, T_{d2} and T_{w2}, respectively, at the end of the roadway can be calculated (the subscript 2 relates to the end of the roadway).

The procedures used to calculate the temperatures at the end of the roadway are as follows:

(i), Separate the total heat Q into "dry" heat, Q_D and "wet" heat, Q_W.

(ii), Express the total heat, Q, in terms of the heat per unit mass of air flow, h_{ML} (kJ/kg),

$$h_{Mt.} = \frac{Q}{m} \tag{5.6}$$

where m = the mass flowrate of air (kg)

(iii), Calculate the water vapour, r_m (kg/kg), produced by the latent heat of evaporation from,

$$r_m = \frac{Q_w}{Lm} \tag{5.7}$$

where L = the latent heat of evaporation (kJ/kg K)

(iv), Calculate the enthalpy, h_1, and mixing ratio, r_1, of the air at the inlet. The enthalpy of the air at the outlet is then given by the sum of the enthalpy of the air at the inlet and the enthalpy from the heat sources in the roadway.

$$h_2 = h_1 + h_{Mt.} \tag{5.8}$$

Similarly, the moisture content of the air at the outlet is the sum of the moisture content of the air at the inlet and the moisture from the latent heat of evaporation.

$$r_2 = r_1 + r_m \tag{5.9}$$

(v), Calculate the dry bulb temperature of the air at the end of the roadway using equation (5.5). Equation (5.5) has to be re-written so that t is on the left hand of the equation. This gives,

$$t = \frac{h_2 - 2500r_2}{4.187(0.24 + 0.45r_2)} \tag{5.10}$$

(vi), Calculate the vapour pressure at the end of the roadway from,

$$e = P\left(\frac{r}{r + 0.622}\right) \tag{5.11}$$

(vii), Calculate the relative humidity of air at the outlet. If the relative humidity calculated exceeds 100 %, the dry bulb temperature has to be re-calculated because the relative humidity of air cannot exceed 100 %. The equation (Maughan, 1988) used to re-calculate the dry bulb temperature is,

$$T_{D2} = T_D + \frac{\frac{3.6}{4}\{e - [0.98 \times svp(T_D)]\}}{1000} \tag{5.12}$$

The corresponding mixing ratio, vapour pressure and relative humidity of the air are also calculated. If the relative humidity is over 100 %, the calculation of the dry bulb temperature using equation (5.12) is repeated until the relative humidity is below 100 %.

(viii) Calculate the wet bulb temperature using equation (5.1). The calculation will require iteration because it is difficult to write the wet bulb temperature, t_w, on the left hand side of equation (5.1). Newton's Method (Gerald, 1978) is recommended in order to increase the speed for convergence. To use the Newton method, equation (5.1) is written as,

$$f(t_w) = e_w + 6.66 \times 10^{-4} \cdot P t_w - (e + 6.66 \times P \cdot t) = 0 \tag{5.13}$$

Differentiation of equation (5.13) gives,

$$f'(t_w) = e'_w + 6.66 \times 10^{-4} P = 0 \tag{5.14}$$

The iteration begins by assuming t_w is equal to the wet bulb temperature at the inlet. The wet bulb temperature at the end of the roadway is then,

$$t_{w2} = t_w - \frac{f(t_w)}{f'(t_w)} \tag{5.15}$$

If t_{w2} is not the same as t_w, set t_{w2} equal to t_w and repeat the calculation, as in equation (5.15), until they agree with each other.

5.2.1 Air Mixing

Ventilation air in underground mines will at some points have two streams of air mixing together at a junction. The temperature of the mixed air can be calculated using the psychrometric equations.

Let the volumetric flowrates of two air streams entering into a junction be Q_1 and Q_2. The flowrate of the mixed stream leaving the junction is Q_3. Also let the temperature of Q1 and Q2 be T_{D1} and T_{W1}, and T_{D2} and T_{W2} respectively. The procedures for calculating the temperature of the mixed stream are as follows:

(i), Calculate the mass flowrate (kg) of Q_1 and Q_2. This is given by the product of the density of the air and the volumetric flowrate.

(ii), Calculate the enthalpy of both air stream , H_1 and H_2, entering into the junction. This is given by the product of the specific enthalpy and the mass flowrate of the air. The specific enthalpy can be calculated from the psychrometric equation (5.5).

(iii), Calculate the moisture contents of both air stream, R_1 and R_2. This is given by the product of the mixing ratio and the mass flowrate of the air.

(iv), Calculate the mass flowrate, the enthalpy and the moisture content of the mixed air. These are,

$$m_3 = m_1 + m_2 \tag{5.16}$$

$$H_3 = H_1 + H_2 \tag{5.17}$$

$$R_3 = R_1 + R_2 \tag{5.18}$$

(v) Calculate the specific enthalpy and the mixing ratio of the mixed air. These are,

$$h_3 = \frac{H_3}{m_3} \tag{5.19}$$

$$r_3 = \frac{R_3}{m_3} \tag{5.20}$$

(vi) Since the specific enthalpy and the mixing ratio of the mixed stream are found, the dry bulb and the wet bulb temperature of the mixed air can be calculated using steps (v) to (viii) in section (5.3).

5.3 PSYCHROMETER

The instrument used for measuring the temperature and humidity of the air is known as a psychrometer. There are two types of psychrometers currently in use in mine ventilation practice, the Sling Psychrometer and the Assman Psychrometer. Both of these instruments provide spot measurements of the dry bulb and wet bulb temperatures of air. For continuous recording of the dry bulb temperature and the humidity of air, a thermohygrograph is used.

The Sling Psychrometer consists of two thermometers, which are fixed on a device. One thermometer measures the dry bulb temperature, and the other measures the wet bulb temperature, of the air. The one measuring the wet bulb temperature has a wick, which is wetted by distilled water, wrapped round the bulb of the thermometer. Evaporation of the water at the surface of the wick will cause a temperature drop. Thus, the wet bulb temperature is lower than the dry bulb temperature. When the Sling Psychrometer is used to measure the temperature and the humidity of air, the device, which has a handle, allows both thermometers to be spinned in the space. The duration of the spinning is approximately 5 minutes.

The Assman Psychrometer also consists of two thermometers, one to measure the dry bulb temperature and one to measure the wet bulb temperature. In addition, a fan is used to draw air through a small duct and direct it over to the bulbs of the thermometers. The advantage of the Assman Psychrometer is that it can be used in a confined space whereas the Sling Psychrometer is difficult to use in a confined space due to the spinning requirement.

A thermohygrograph is shown on the photograph. This is a mechanical device for continuously recording the temperatures and humidities of air on a daily and weekly basis. The temperature and humidity are recorded on a chart which is attached to the rotating drum of the instrument. Since the temperature and humidity are recorded on a paper chart, it is necessary to calibrate the instrument every time it is installed and removed. The steps for calibrating the thermohygrograph are as follows:

(i), Unscrew the nut which secures the rotating drum in the Thermohygrograph and remove the drum from the instrument.

(ii), The Thermohygrograph chart is wrapped round and clipped on to the drum.

(iii), Put the drum back into the instrument and screw down the nut securing the drum. Ensure that the pens are over the metal strip which keeps the chart on the drum.

(iv), Wind the timer up.

(v) Hang an Assman psychrometer, where practicable and possible, in the middle of the roadway. Wind up the timer to operate the fan in the psychrometer. Ensure that the wick, attached to the wet bulb thermometer, is wetted thoroughly with distilled water.

(vi) Record the temperature readings, dry bulb and wet bulb temperature of the air, every 5 minutes for half an hour.

(vii) Convert the wet bulb temperature to the wet bulb depression and then find the relative humidity either by a psychometric chart or psychometric equation. It is recommended that a table is available which gives the relative humidity with respect to the wet bulb depression and the dry bulb temperature.

(viii), Set the dry bulb temperature on the thermohygrograph first and set the relative humidity.

(ix), Once the temperature and humidity are adjusted, the thermohygrograph can be hanged and clamped on an arch in a roadway.

(x), The thermohygrograph can then be left either for 24 hours or for a week. Before the chart is removed from the thermohygrograph, the Assman Psychrometer is used to measure the dry bulb and the wet bulb temperatures. The temperature readings should be made every 5 minutes for half an hour.

and (xi), The chart is removed from the thermohygrograph. The data on the chart is then digitised and processed using the programmes (HQTD) at HQTD to convert results to temperature readings.

CHAPTER SIX

COMPUTER MODEL

The traditional technique used by British Coal to produce temperature predictions, for an underground roadway, is based on the StBV programme (Voss, 1969). This programme is a steady-state programme (Browning et al, 1977), in that the air temperature in underground roadway is assumed to be constant over the ventilated age of the roadway. The same technique was adopted by Maughan (1988) for his development of a steady-state programme, from which temperature predictions were produced for a mine ventilation network. The advantages in using this steady-state programme for predicting air temperatures are that it is simple to use and produces reasonably accurate predictions. On the other hand, the programme usually gives a high estimate for the strata heat flow. As the capital cost of providing an acceptable working environment is increasing, there will be demand for a computer programme , which is able to produce more accurate temperature predictions.

A transient computer programme is developed for predicting transient temperatures in an underground roadway. This programme is constructed from the programmes developed for the calculation of the heat flow from strata (Cheung, 1988) and conveyed coal (Cheung and Rabia, 1988), the mathematical model developed by Maneylaws (1988) for the storage effect in structural steel, and the empirical equations developed by Browning et al (1988).

The transient programme for predicting transient temperatures in an underground roadway is programmed in a high level computer language, Fortran-77, in the main frame computer, Amdalh 9600, installed at the University of Newcastle upon Tyne, U.K. The programme can be compiled by running a software programme, either *Fortranvs or *IF77 (NUMAC). Both *Fortranvs and *IF77 are Fortran 77 compiler software installed in the same computer. Moreover, the transient programme can also be compiled using Pro-Fortran 77 in any IBM micro computer or compatible. The execution of the compiled programme normally takes less than two minutes. When the programme is executed in a micro-computer, the execution time is very long.

Execution of the programme requires an input data file (Appendix II), in which all the data required to run the programme are entered. The datafile name is entered as soon as the execution of the programme begins. If the datafile is not found, the programme will stop automatically. When the execution of the programme is completed, an output file is created immediately with the echo of the input data and the temperature predictions (Appendix III).

The computer code of the programme is shown in Appendix I. It consists of a main program and seventeen subroutines in which all the variables, with units, are described in the comment lines in the programme. Since this programme has over 1200 lines, flowcharts are used to describe the algorithm of the programme. The last subroutine is called Blockdata. This subroutine consists of all the constants used in the programme. Examples of these include the thermal properties of strata, conveyed coal and steel.

6.1 MAIN PROGRAMME

The main programme (Figure 6.1) controls the flow of each subroutine in the programme. In addition, the output of results is produced.

Variables declared in the main programme are called global variables. These are described in Appendix IV. It is important that the global variables in the main programme should not be confused with those used in the subroutines. The variables used in the subroutines are known as local variables. Their values depend on what global variables are used when calling the subroutines.

6.2 FUNCTION EFFTEM

Function EFFTEM (Figure 6.2) calculates the basic effective temperature of air. The code in this subroutine is obtained from the programme developed by Maughan (1988).

The input arguments of this function are air velocity, dry bulb and wet bulb temperatures. The output of this function is the basic effective temperature. The basic effective temperature is a measure of the legal limit for a mineworker working in underground mines.

6.3 SUBROUTINE INPUT

Subroutine INPUT (Figure 6.3) reads data from the datafile. The data to be read from the datafile should be in the same format as required by the programme. The datafile is described in Appendix II.

The input arguments of this subroutine are PI and SCONV. The output arguments are RADIUS and IFCOAL. The transfer of the input data between the subroutine and the main programme is done by using the common block called RINPUT, which is a command in Fortran for easy transfer of data between subroutines. The variables used in this common block are the same as those declared in the main programme.

6.4 SUBROUTINE RPOWER

Subroutine RPOWER (Figure 6.4) is a separate subroutine for entering the power rating of individual machinery in a roadway. The data will also appear in the datafile. This subroutine can only be called from the subroutine INPUT.

The input arguments of this subroutine are NP, MP and NPOWER. NP is the number of individual power sources in the roadway. MP, which is the same as IDATA(2), is the number of sections. NPOWER is a one dimensional array with 84 elements, and it indicates whether there is machinery installed in the roadway.

The output arguments are PRATE and PPART. Both variables are a two dimensional array with a total of 840 elements. PRATE is the rating of machinery power and PPART is the proportion of power appearing as heat.

6.5 SUBROUTINE INIT

Subroutine INIT (Figure 6.5) calculates the actual time interval required for the ventilated age of a roadway. The age of the roadway is in hours and it is divided into 84 elements with a 2 hourly interval for a production week and 84 elements with a 2 hourly interval for a conditioning week. The remaining time, which is known as the past history, is further divided into 40 elements. In addition, strata temperature at each section of the roadway is initialised.

The input arguments of this subroutine are NAWT, N and RDATA. NAWT is the type of airway. N is the number of the section. RDATA is an array of roadway data.

The output arguments are RAYAGE and RAYVST. Both are a one dimensional array. RAYAGE is an array of the age of the roadway. RAYVST is an array of virgin strata temperature at each section of the roadway.

6.6 SUBROUTINE SAGE

Subroutine SAGE (Figure 6.6) calculates the non-dimensional time, that is the Fourier number, for the calculation of the surface temperature of roadway strata. In addition, the temperature function and the mean of the adjacent temperature function are calculated by calling subroutine SDELTA.

The input arguments of this subroutine are NCON, TROCK, CPROCK, RHOROC, RADIUS and AGE. NCON is the number of the conditioning week. TROCK is the thermal conductivity of strata. CPROCK is the specific heat capacity of strata. RHOROC is the density of strata. RADIUS is the radius of the roadway. AGE is the ventilated age of the roadway.

The output arguments are FI, FIMEAN and NTERM. FI is the temperature function of strata. FIMEAN is the mean temperature function of strata. NTERM is the number of the time elements.

6.7 SUBROUTINE STEEL

Subroutine STEEL (Figure 6.7) calculates the steel temperature and the heat emitted by structural steel in a roadway. The subroutine is called from the main programme.

The input arguments in this subroutine are TTDRY, TTWET, SETA, STDATA, NSECT. TTDRY is an array of the dry bulb temperature of air. TTWET is an array of the wet bulb temperature of air. SETA is an array of the wetness factor of the roadway. STDATA is an array of steel data. NSECT is the number of the section in the roadway. Common block, STLCON, is used to transfer the steel constant.

The output arguments are QSTLT and QSTLW. QSTLT is the total heat emitted by the steel. QSTLW is the 'wet' heat from the steel.

6.8 SUBROUTINE COAL

Subroutine COAL (Figure 6.8) calculates the surface temperature of a continuous slab of conveyed coal and the heat emitted from the coal. The subroutine is called from the main program.

The input arguments in this subroutine are CDATA, TON, TTDRY, TTWET, NCONV, VDATA, NSECT, IVENT. CDATA is an array of the data for the conveyed coal. TON is an array of the coal output during four working shifts in a day. TTDRY is an array of the dry bulb temperature of air. TTWET is an array of the wet bulb temperature of air. VDATA is an array of air velocity. NSECT is the numbers of section in a roadway. IVENT is the same as IDATA(3), and indicates the types of ventilation. Common blocks, STRATA, AIRCON and COLCON are used to transfer the constants of strata, air and coal to the subroutine.

The output arguments are AVEQCW and AVEQCT. AVEQCW is an array of an average of the 'wet' heat from the conveyed coal. AVEQCT is an array of an average of the total heat from the conveyed coal.

6.9 SUBROUTINE CDELTA

Subroutine CDELTA (Figure 6.9) calculates the temperature function, and the mean temperature function, of the conveyed coal.

The input arguments of this subroutine are N, BLEN, RELVEL, BTHICK, CRHO, CCOAL, CPCOAL. N is the number of the section. BLEN is the length of the conveyor belt. RELVEL is the relative velocity. BTHICK is the thickness of the conveyed coal. CRHO is the density of the conveyed coal. CCOAL is the convective heat transfer coefficient of coal. CPCOAL is the specific heat capacity of coal. Common block, STRATA, transfers the strata constants to the subroutine.

The output arguments are CF and CFMEAN. CF is the temperature function of the conveyed coal. CFMEAN is the mean temperature function of the adjacent temperature function.

6.10 SUBROUTINE SDELTA

Subroutine SDELTA (Figure 6.10) calculates the temperature function, and the mean temperature function, of strata.

The input arguments of this subroutine are S and MT. S is an array of time in the main programme. MT. is the number of the time element.

The output arguments are D and DMEAN. D is the temperature function of strata. DMEAN is the mean of the temperature function of strata.

6.11 SUBROUTINE STEMP

Subroutine STEMP (Figure 6.11) initialises the air temperature and wetness factor over each time interval.

The input arguments of this subroutine are SETA, NSECT, NCON, TTDRY and TTWET. SETA is an array of the wetness factor. NSECT is the number of the section in a roadway. NCON is the number of the conditioning week. TTDRY is an array of the dry bulb temperature of air. TTWET is an array of the wet bulb temperature of air.

The output arguments are DRY1, WET1 and ETA. DRY1 is an array of the dry bulb temperature of the air at the inlet of a sectioned roadway. WET1 is an array of the wet bulb temperature for the same sectioned roadway. ETA is an array of the wetness factor for the same roadway.

6.12 SUBROUTINE TSOLID

Subroutine TSOLID (Figure 6.12) calculates the surface temperature of strata and conveyed coal according to the numerical method developed by Jordan (1961).

The input arguments of this subroutine are ITYPE, BBDRY, BBWET, ETA,

CF, CFMEAN, N, TZERO, TROCK, RADIUS. ITYPE is the type of calculation of surface temperature for either strata or conveyed coal. BBDRY is an array of dry bulb temperature. BBWET is an array of wet bulb temperature. ETA is an array of wetness factor. CF is the temperature function. CFMEAN is the mean temperature function. N is the number of elements in the array. TZERO is either the virgin strata temperature or the initial coal temperature. TROCK is the thermal conductivity of strata. RADIUS is the radius of the roadway.

The output argument is TCOAL, which is the surface temperature of either strata or conveyed coal.

6.13 SUBROUTINE EVAP

Subroutine EVAP (Figure 6.13) calculates the heat flux of a partially wetted surface. This can be either for the surface of the strata or for the conveyed coal.

The input arguments of this subroutine are DB, WB, TSURF, ETA, CONV and RAD. DB is dry bulb temperature. WB is wet bulb temperature. TSURF is the assumed surface temperature. ETA is the wetness factor. CONV is the convective heat transfer coefficient either for strata or conveyed coal. RAD is the radiation heat transfer coefficient.

The output arguments are QFLUX, C and SIGMA. QFLUX is the heat flux. C is the constant for the heat transfer coefficient. SIGMA is the temperature used in equation (3.55).

6.14 SUBROUTINE CALTEM

Subroutine CALTEM (Figure 6.14) calculates the change in temperature due an increase in the enthalpy of the air.

The input arguments of this subroutine are AMASS, DB1, WB1, QT and

QWET. AMASS is the mass of air. DB1 is the initial dry bulb temperature. WB1 is the initial wet bulb temperature. QT is the total heat flux. QWET is the total wet heat flux.

The output arguments are DB2 and WB2. DB2 is the final dry bulb temperature. WB2 is the final wet bulb temperature.

6.15 SUBROUTINE WETBUL

Subroutine WETBUL (Figure 6.15) calculates the wet bulb temperature.

The input arguments of this subroutine are D, RH, PAIR, ENT and GW. D is dry bulb temperature. RH is relative humidity. PAIR is partial air pressure. ENT is the enthalpy of air. GW is an assumed wet bulb temperature.

The output argument is W, which is wet bulb temperature.

6.16 SUBROUTINE AIRMIX

Subroutine AIRMIX (Figure 6.16) calculates the temperature of two streams of air mixed together.

The input arguments of this subroutine are Q1, D1, W1, Q2, D2 and W2. Q is volumetric flow rate. D is dry bulb temperature. W is wet bulb temperature. 1 and 2 are the numbers for two separate streams of air.

The output arguments are Q3, D3 and W3. Q3 is the final volumetric flowrate. D3 is the final dry bulb temperature. W3 is the final wet bulb temperature.

Figure 6.1 The Main Programme

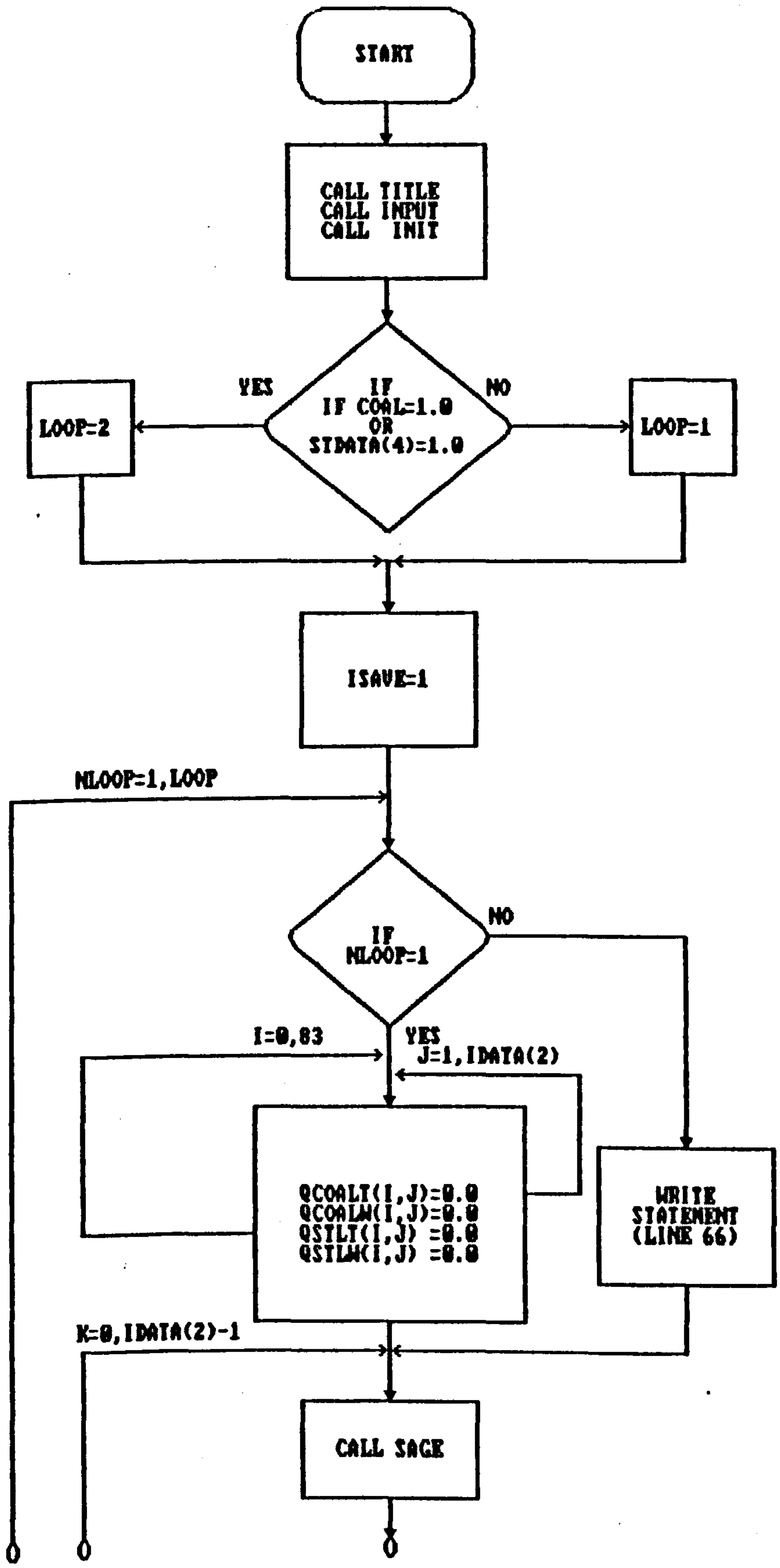


Figure 6.1 Continue...1

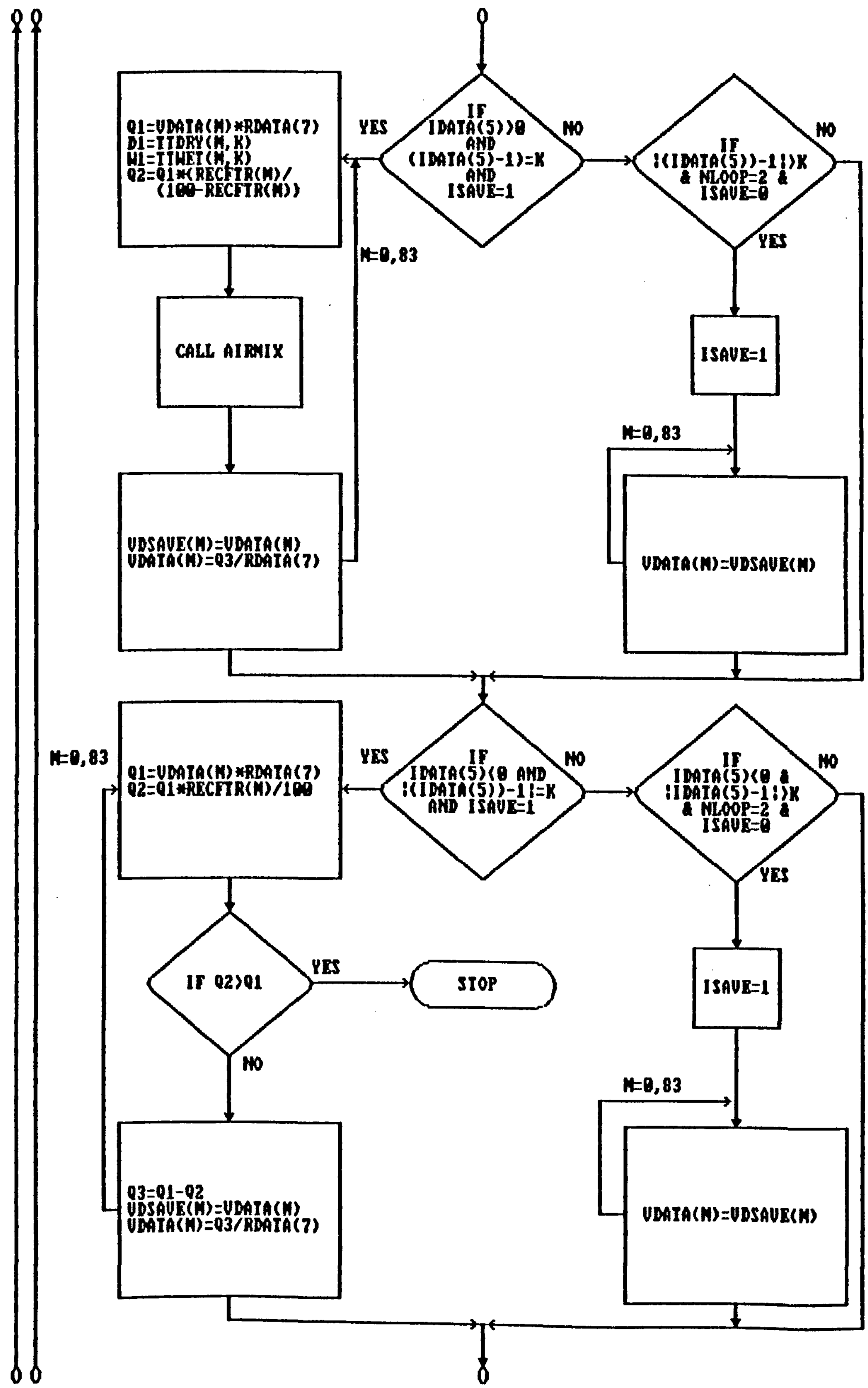


Figure 6.1 Continue...2

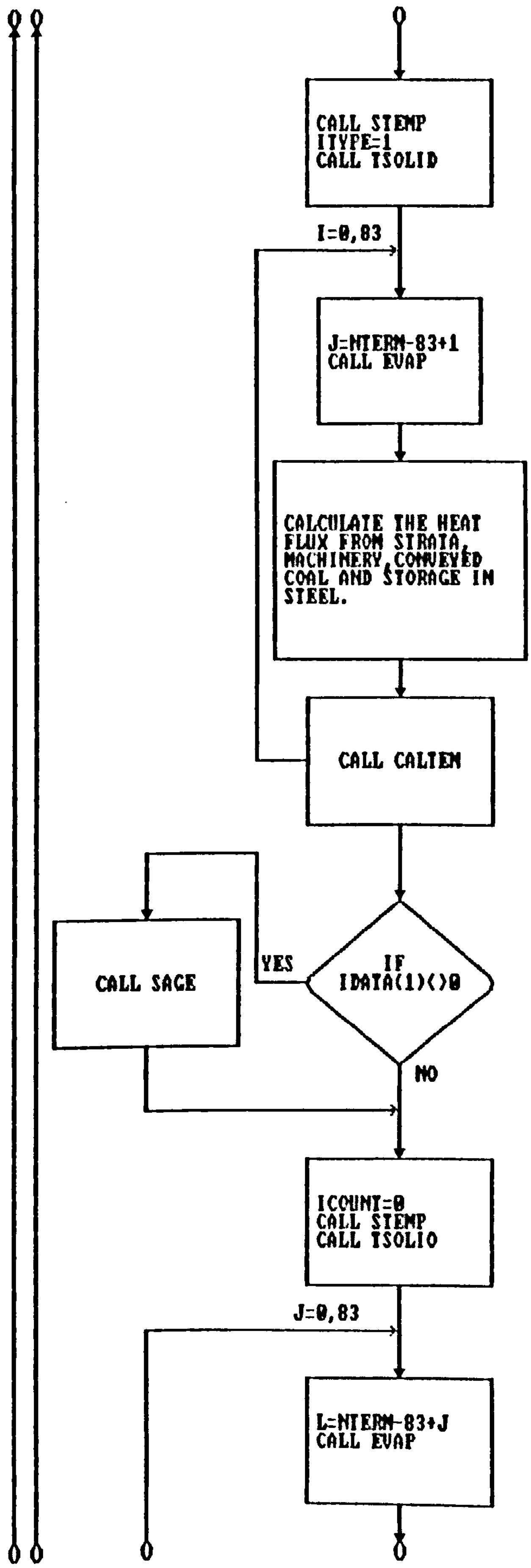


Figure 6.1 Continue...3

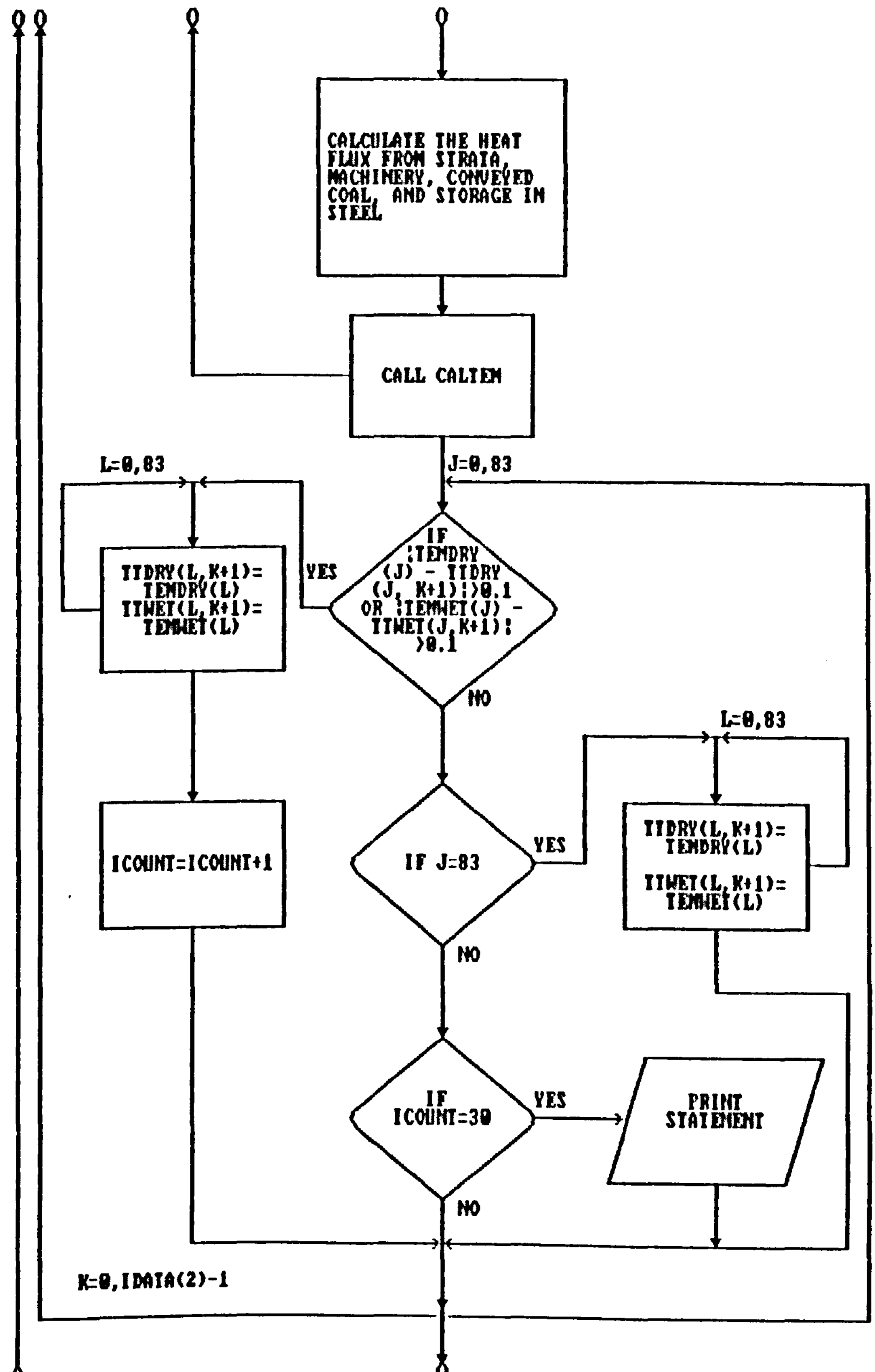


Figure 6.1 Continue...4

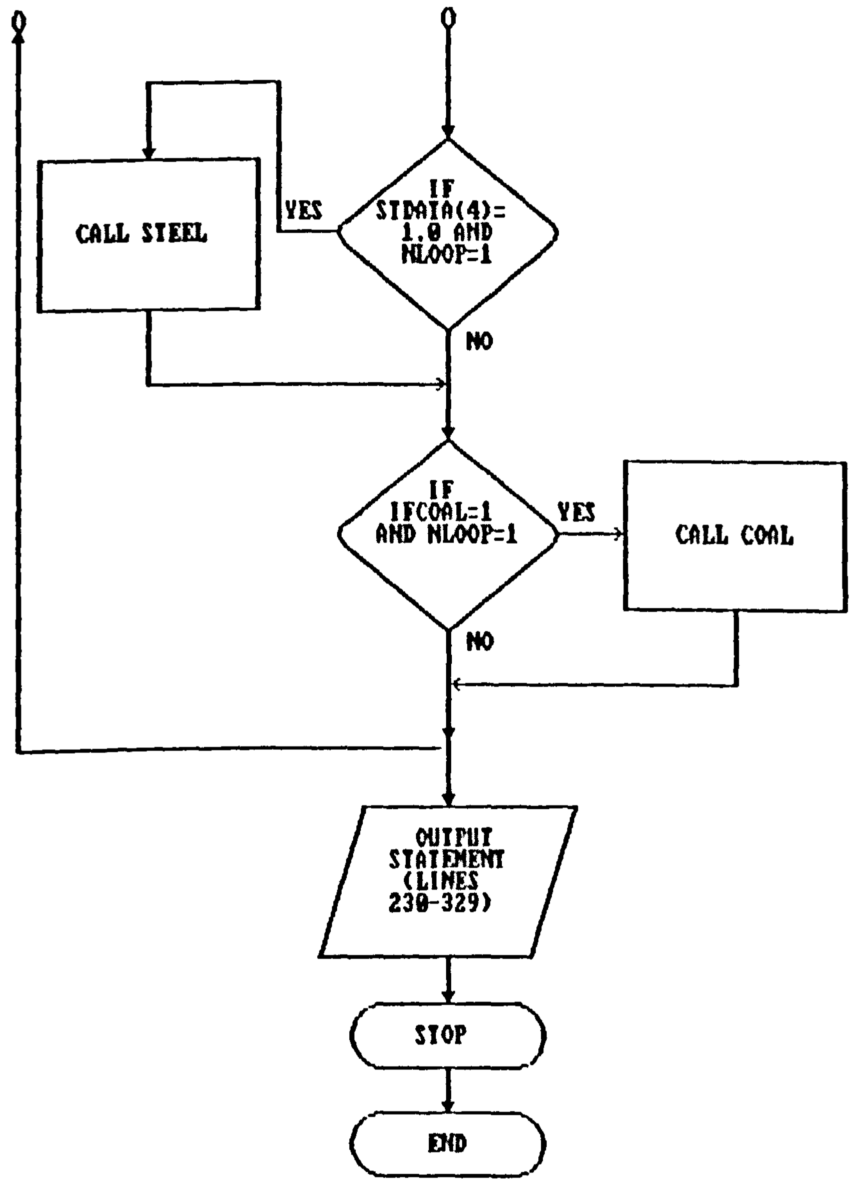


Figure 6.2 FUNCTION EFFTEM

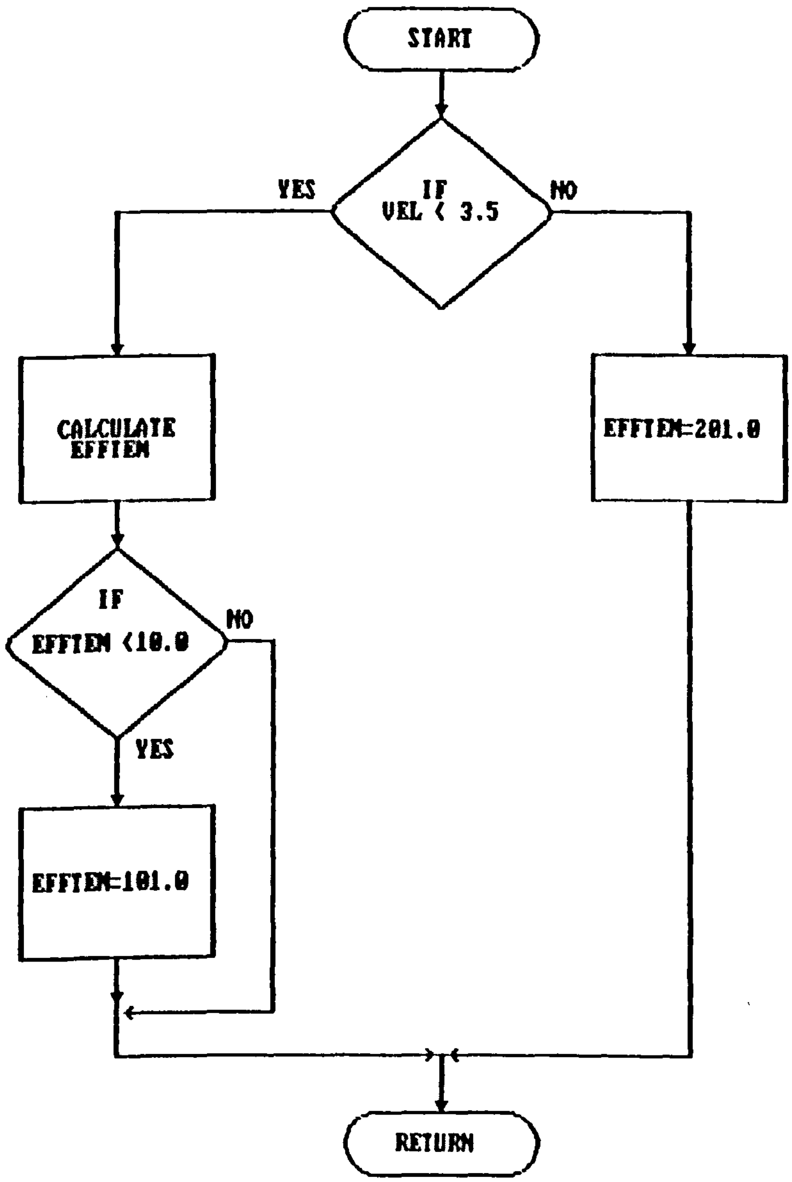


Figure 6.3 SUBROUTINE INPUT

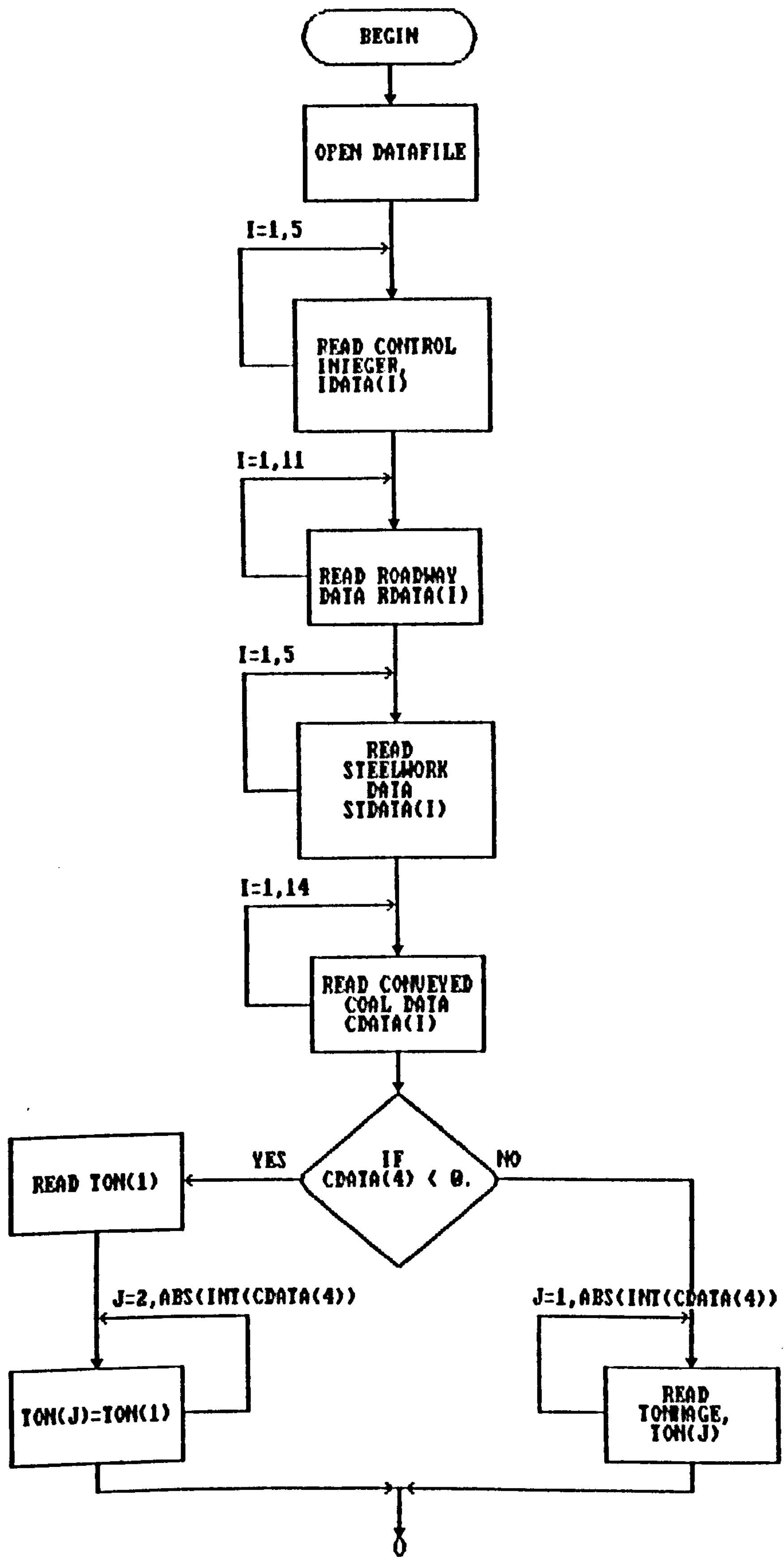


Figure 6.3 Continue...1

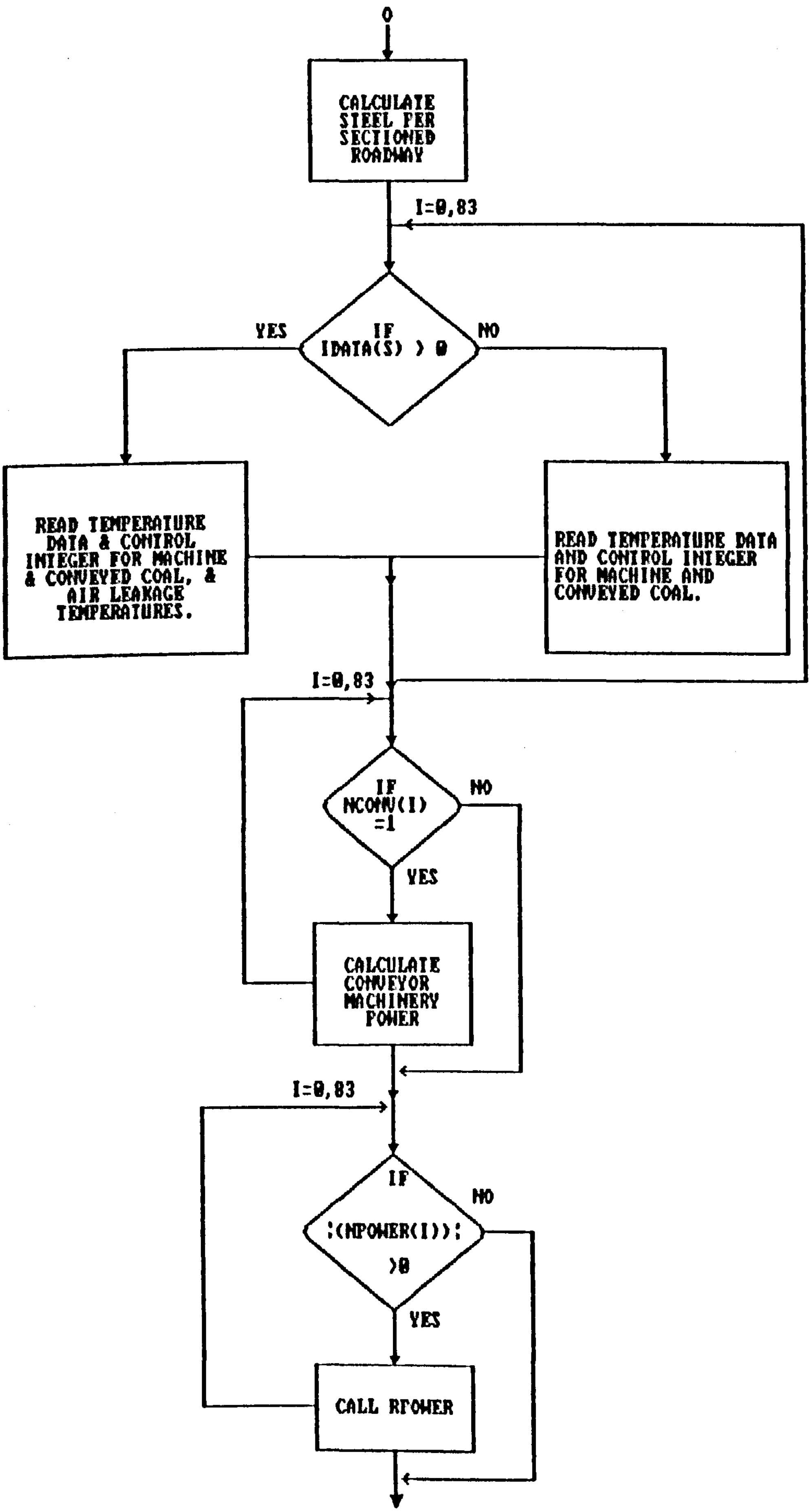


Figure 6.3 Continue...2

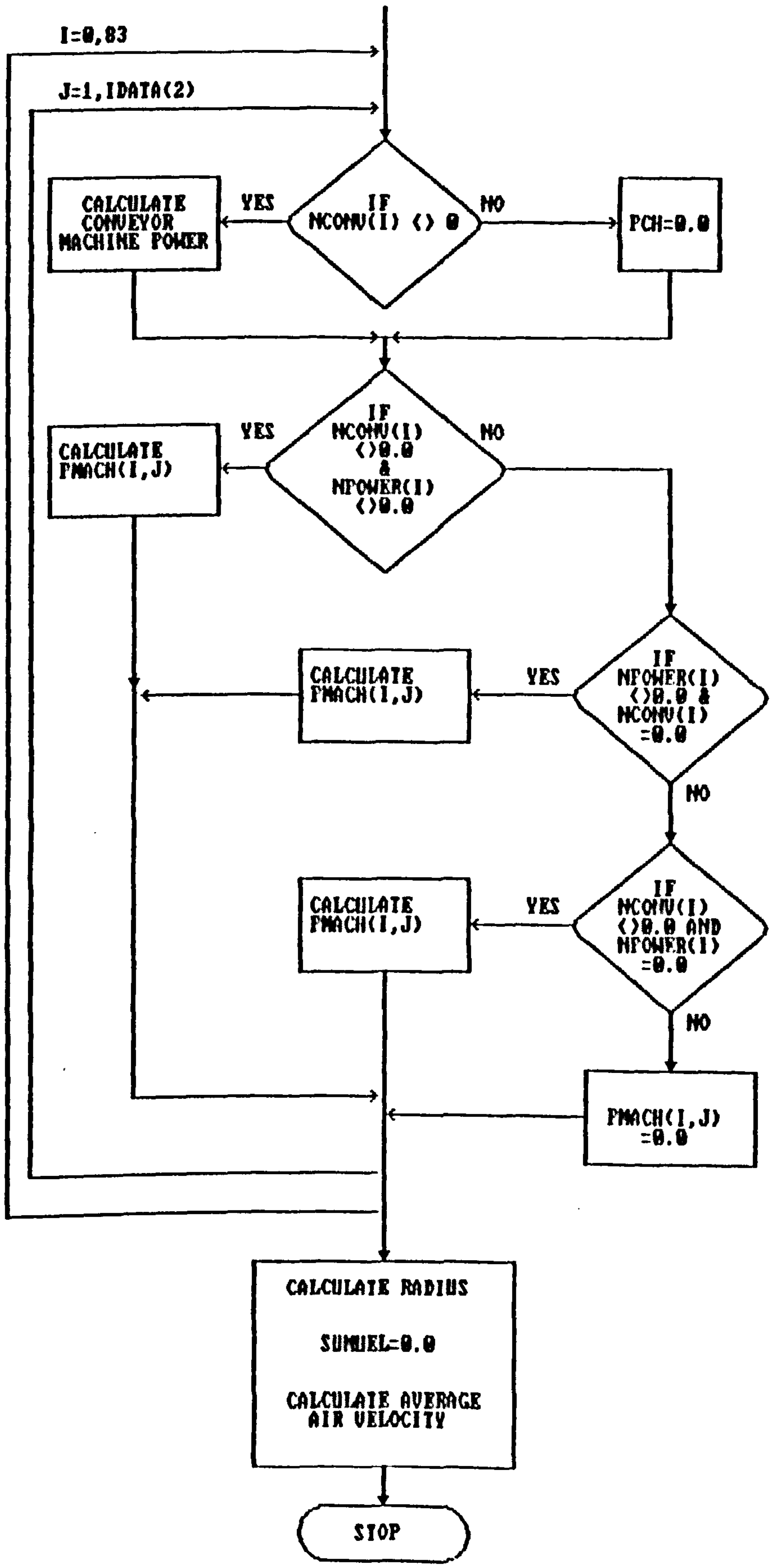


Figure 6.4 SUBROUTINE RPOWER

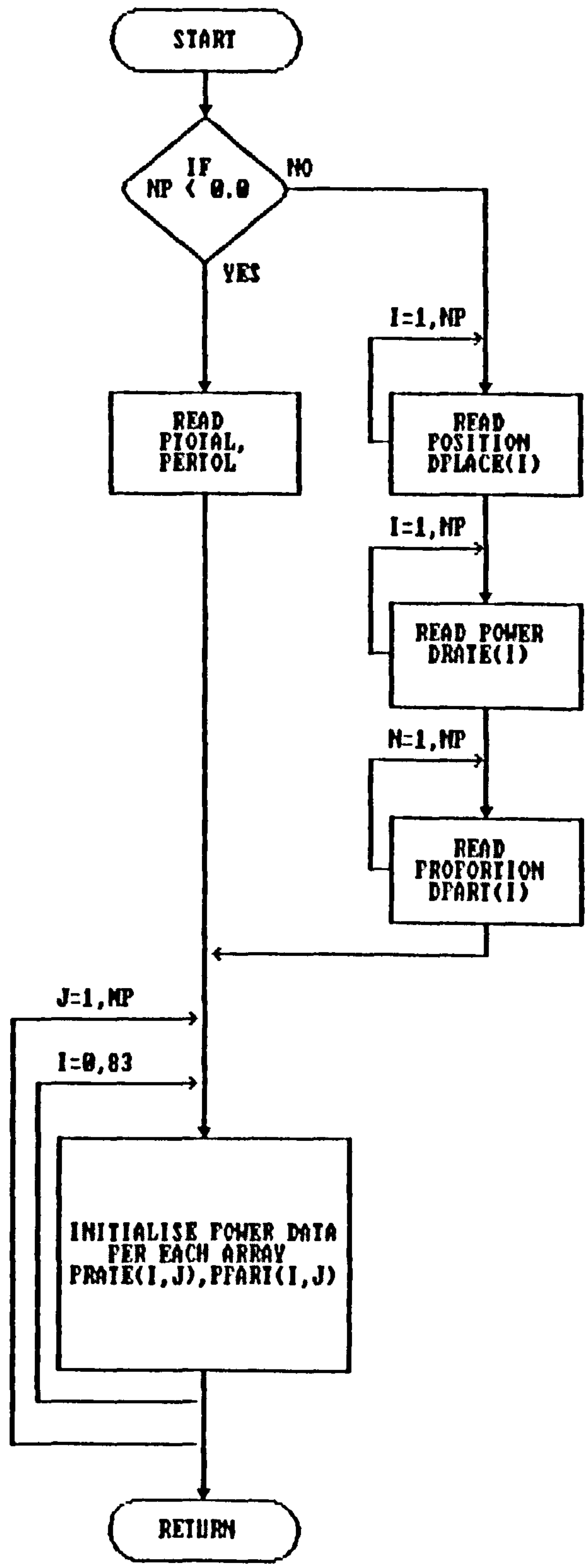


Figure 6.5 SUBROUTINE INIT

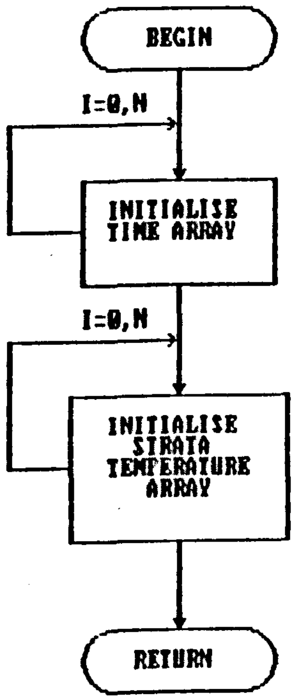


Figure 6.6 SUBROUTINE SAGE

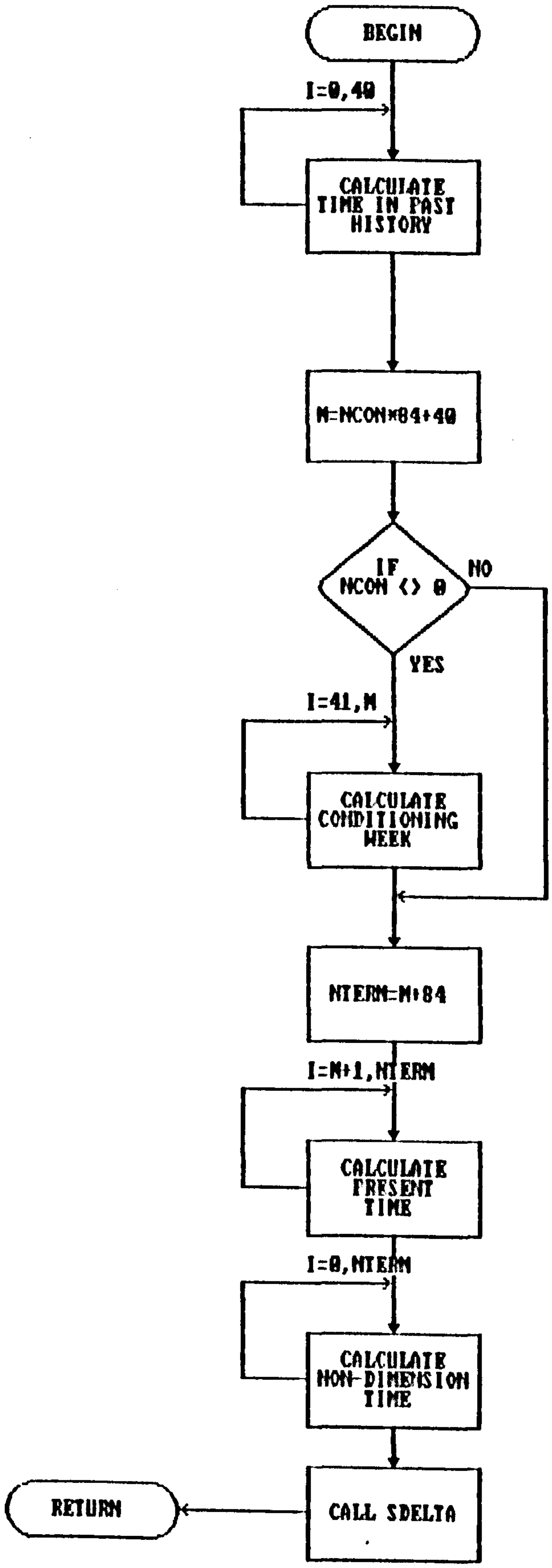


Figure 6.7 SUBROUTINE STEEL

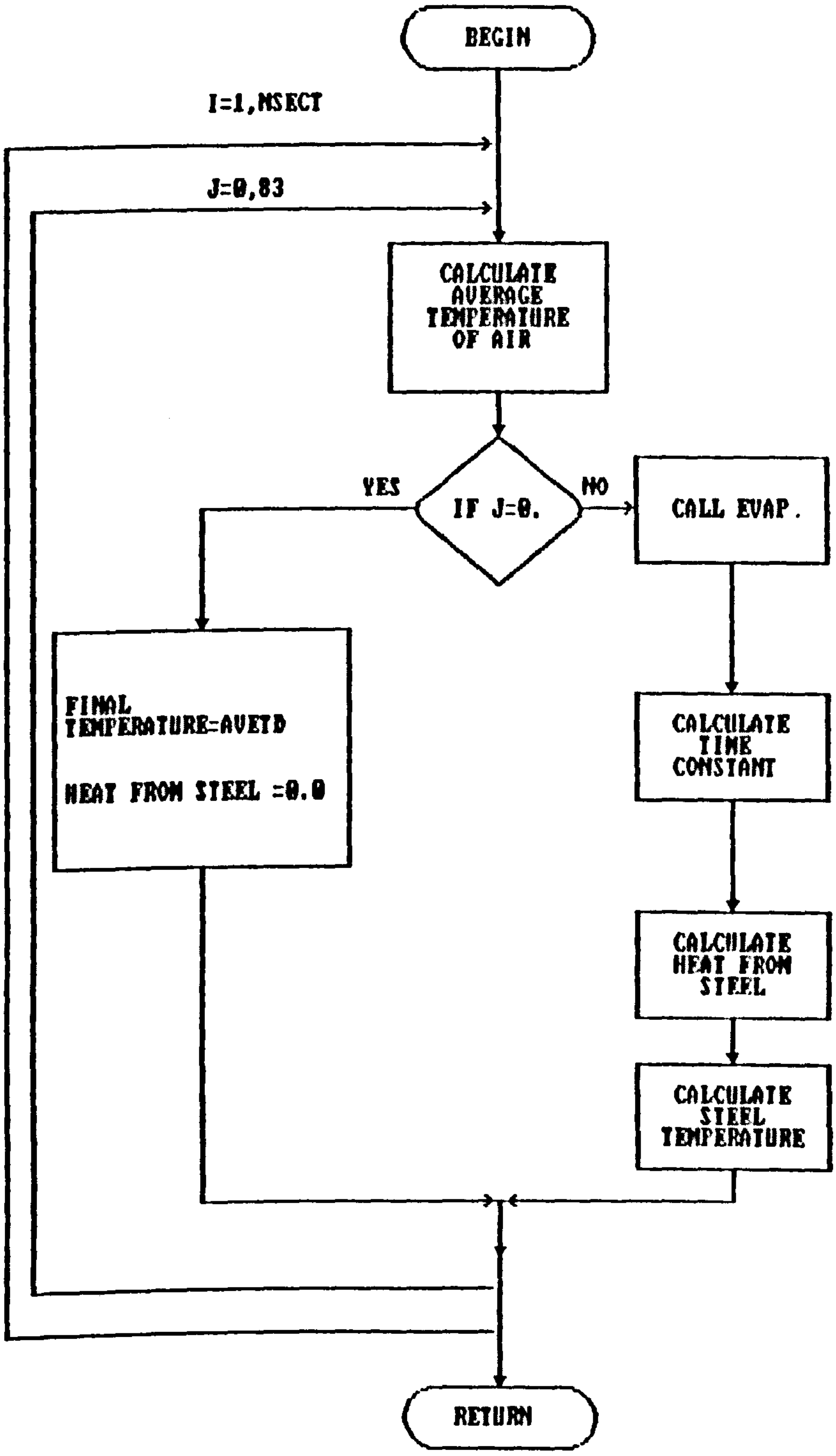


Figure 6.8 SUBROUTINE COAL

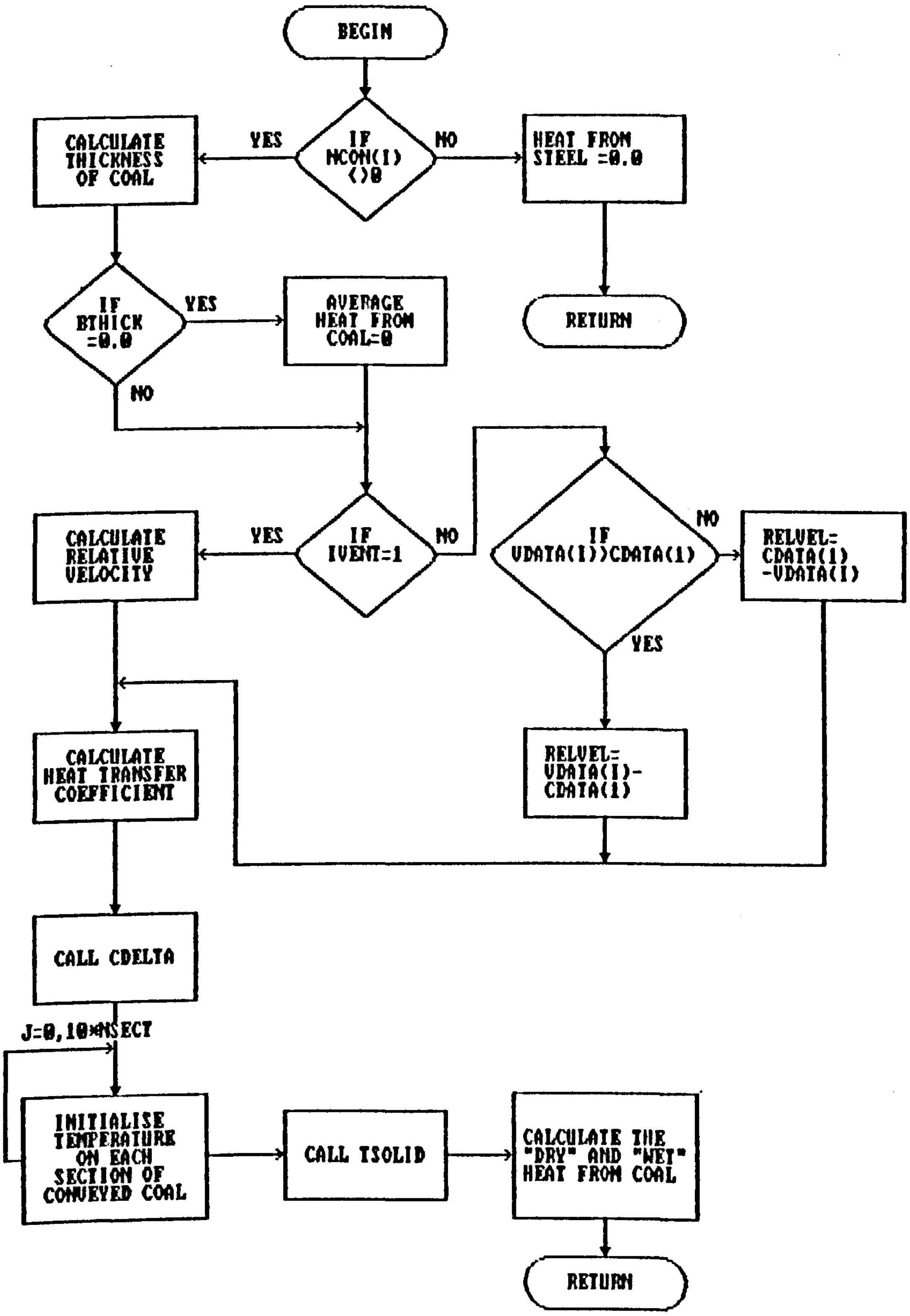


Figure 6.9 SUBROUTINE CDELTA

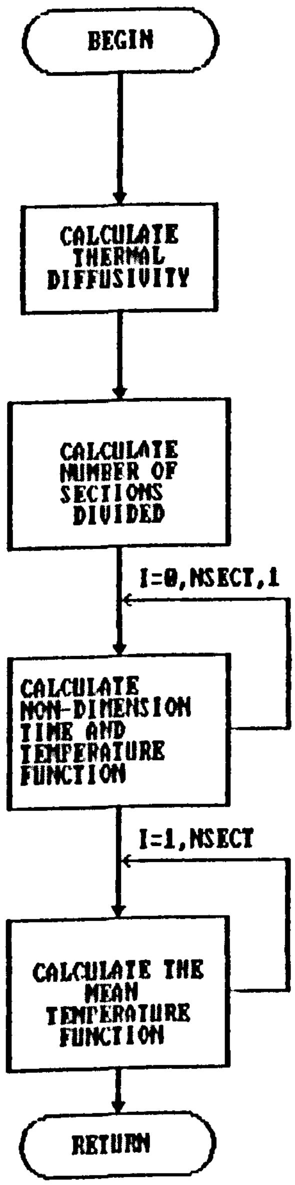


Figure 6.10 SUBROUTINE SDELTA

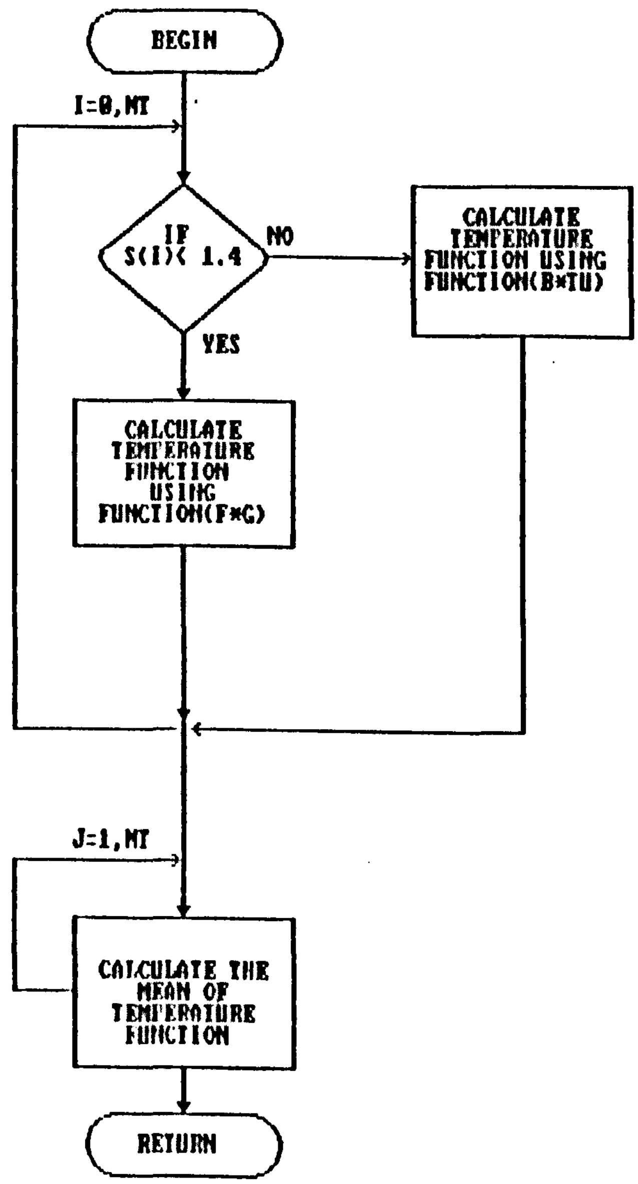


Figure 6.11 SUBROUTINE STEMP

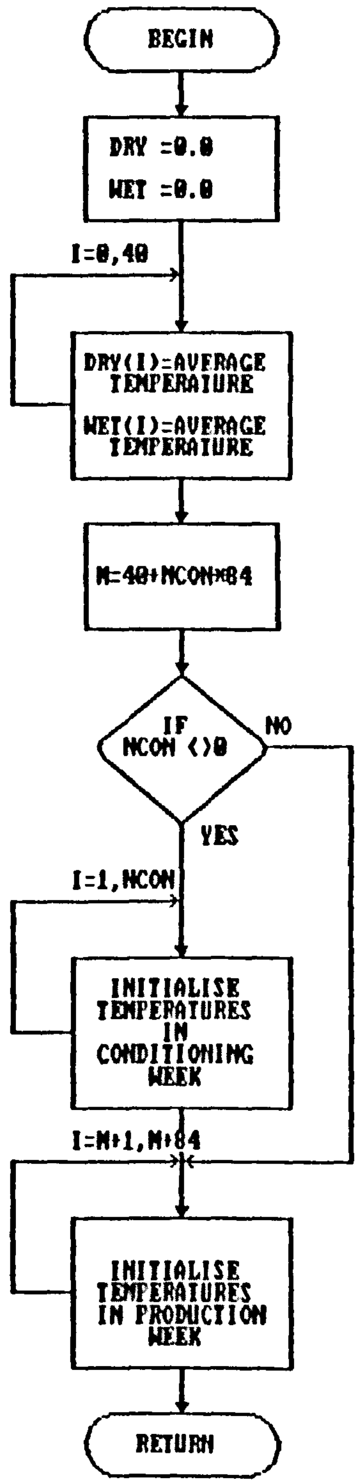


Figure 6.12 SUBROUTINE TSOLID

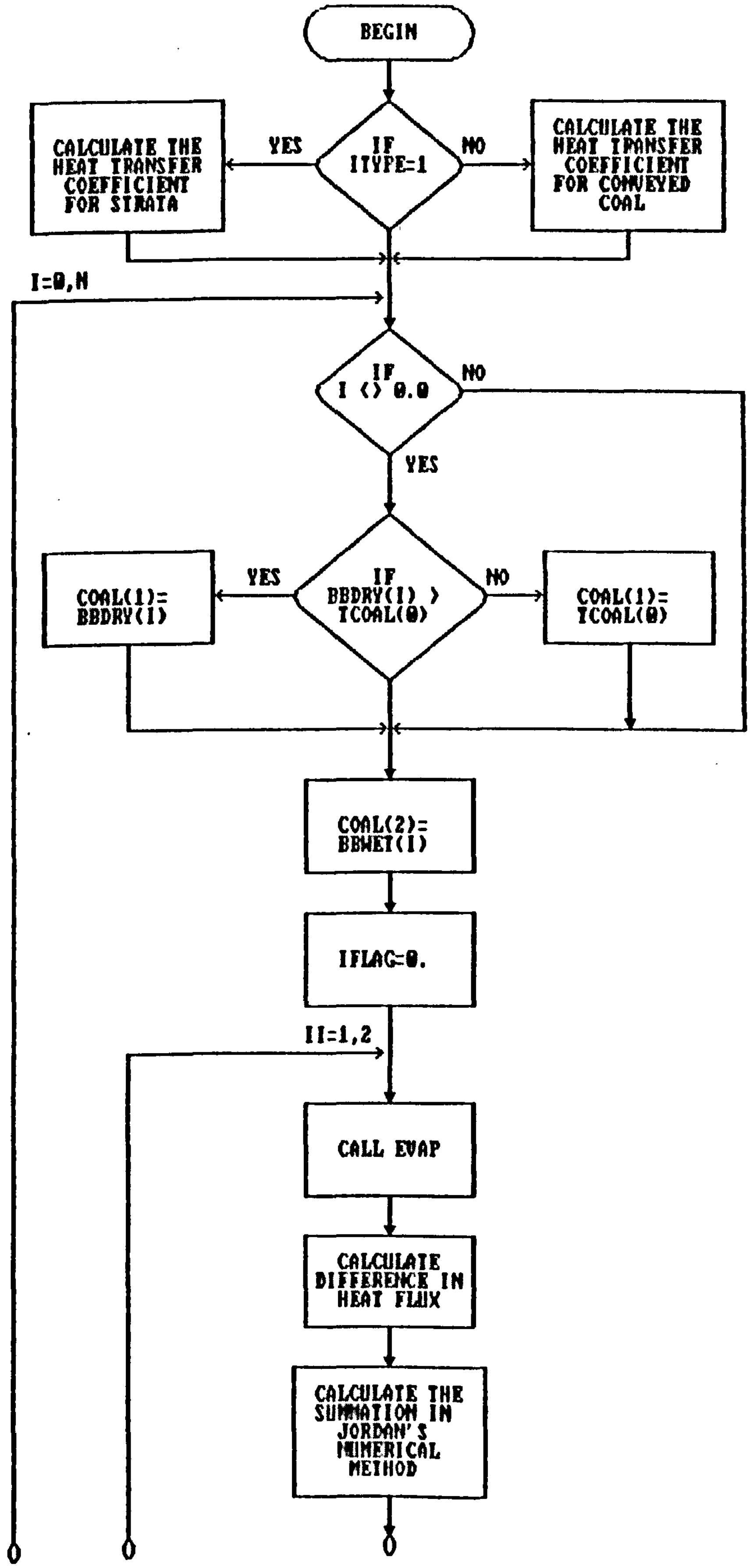


Figure 6.12 Continue...1

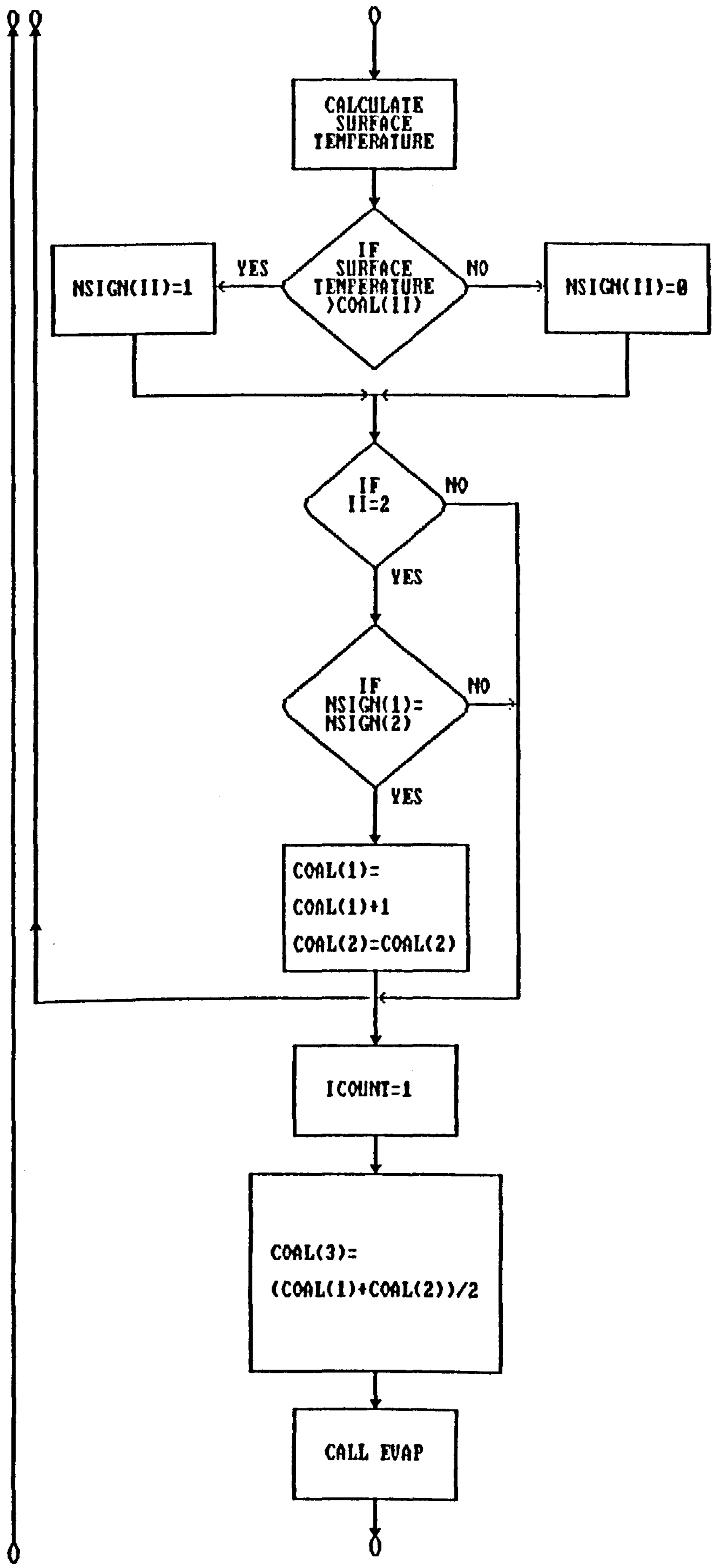


Figure 6.12 Continue...2

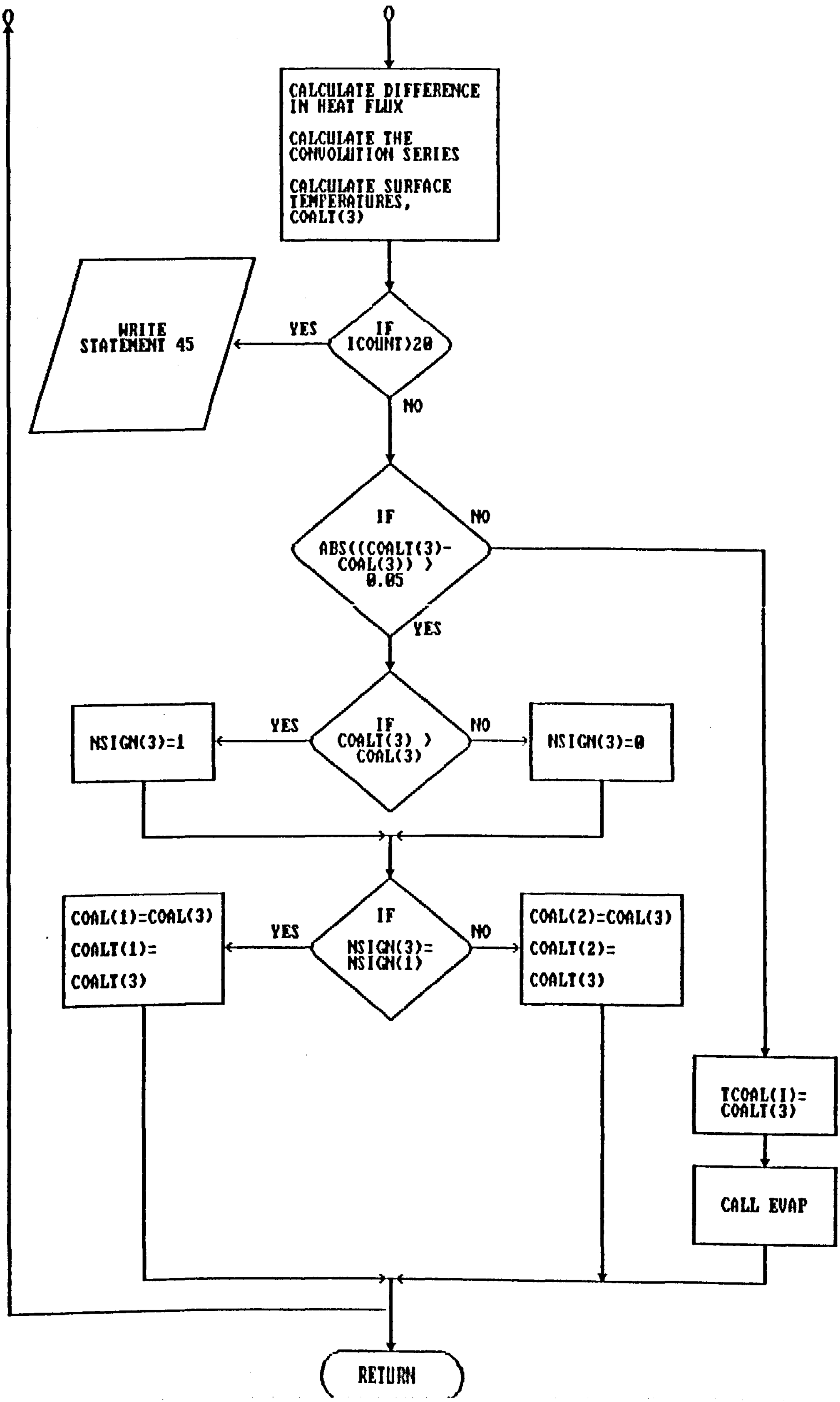


Figure 6.13 SUBROUTINE EVAP

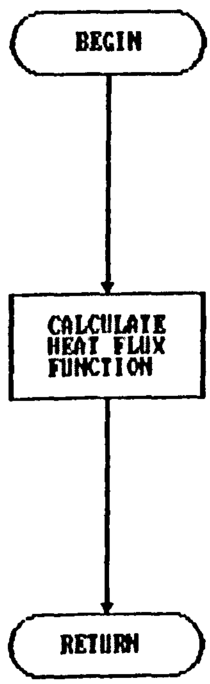


Figure 6.14 SUBROUTINE CALTEM

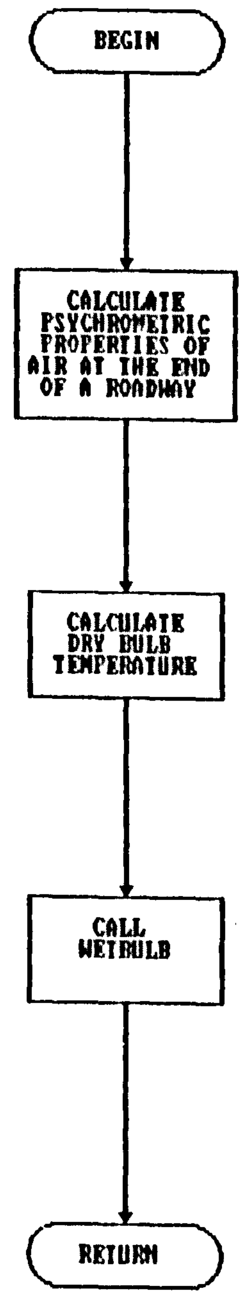


Figure 6.15 SUBROUTINE WETBUL

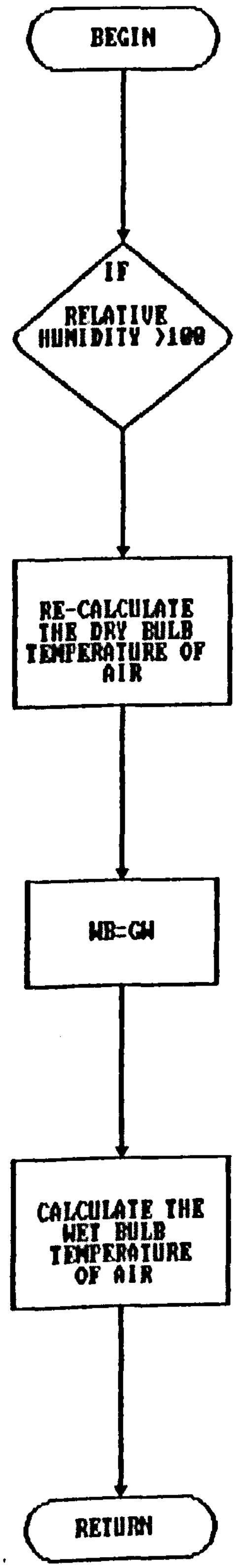
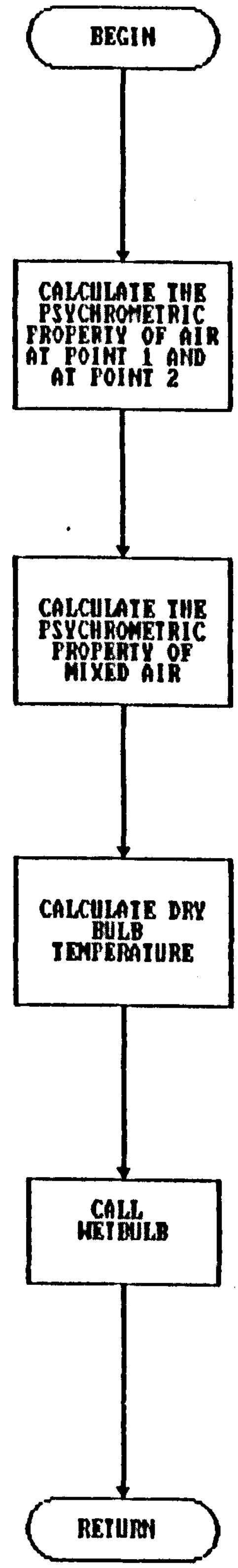


Figure 6.16 SUBROUTINE AIRMIX



CHAPTER SEVEN

CLIMATIC INVESTIGATIONS

A computer programme to predict weekly air temperatures for an underground roadway has been developed. In order to use the programme to assist in future mine ventilation planning, it is necessary to validate the programme by comparing the predicted temperatures with the actual temperatures obtained in an underground roadway. Actual temperatures were obtained from temperature surveys undertaken at three sites at Wearmouth Colliery, Sunderland, U.K., and at a site at Whitemoor Colliery, Selby, U.K.

The temperature surveys were undertaken with assistance provided by the technical staff of British Coal at the collieries and at the Headquarter and Technical Department (HQTD), Bretby, U.K. The surveys were carried out first at the three sites at Wearmouth Colliery, and then at the site at Whitemoor Colliery. The instruments used for these surveys were, (i), thermohygrographs for continuous recordings of the air temperature and humidity, (ii), an Assman psychrometer for calibrating the thermohygrograph, (iii), an anemometer for measuring air velocity, and (iv), a rule for measuring the dimension of the roadway. The surveys involved installation and calibration of thermohygrographs, and measurements of air velocity and roadway dimensions, at the sites.

The temperature surveys undertaken, at the three sites at Wearmouth Colliery took place over a period of ten weeks. This was due to the fact that only six thermohygrographs, which were provided by HQTD, were available. For this reason, the surveys were carried out first at the main drift and then at the conveyor roadway. Once satisfactory recordings of the air temperature and humidity were achieved, the instrument were transferred to the third site, an advance face working district, H101s.

The site where temperature surveys were undertaken at Whitemoor Colliery is a working district called B2. This district consisted of a retreating face, together with the maingate and tailgate of the same face. The survey carried out at the site was completed, with assistance from the technical staff at the colliery and at HQTD, within a period of three weeks. The site was chosen, in addition to those at Wearmouth Colliery, because the district has a higher virgin strata temperature than that of Wearmouth Colliery, and is a working district operating under a different mining technique, a retreat face working.

7.1 SITE DETAILS

The three sites, where temperature surveys were carried out at Wearmouth Colliery, are as follows:

(1), A length of 500m roadway in the main drift. This roadway is used mainly for the manrider, with occasional use by diesel locomotives. This section of the main drift was chosen because the heat flow into this section occurs only from strata. The heat from the manrider and diesel locomotives is considered to have an insignificant effect on the air temperature.

(2), A length of 400m conveyor roadway in the main belt line. The conveyor belt in this roadway operates continuously and transports coal outbye. The heat flow into this section of roadway includes the heat from conveyed coal, conveyor machinery and surrounding strata.

(3), The maingate and tailgate of a production face. This is an advance face which is antitropally ventilated with local recirculation at the headings. Both the maingate and tailgate have conveyor belts. The former conveys coal production outbye. and the latter conveys material from the heading.

The site at Whitemoor Colliery consisted of the maingate and tailgate, of a retreat face. The district is antitropally ventilated, with ventilation air entering at the maingate and coal production transported outbye in the same gateroad. No conveyor machinery was installed at the tailgate.

The Wearmouth and Whitemoor Colliery sites were chosen to cover low and high virgin strata temperatures, respectively. Moreover, since the working districts at each colliery utilised different mining methods, it is possible to compare the temperature predictions for the gateroads in an advancing and a retreating face.

7.2 MEASURING TECHNIQUES

Mechanical devices, thermohygrographs, were used for continuous measurements of air temperature and humidity in the underground roadways. The thermohygrograph was placed inside a cage, to protect the instrument from damage, while it was installed at the sites where the temperature surveys were undertaken. At each thermohygrograph station, the instrument was secured to one side of a roadway arch. In the case of the thermohygrograph installed at the inbye end of a gateroad, the instrument was secured on the brackets of a power-pack at the inbye end of the gateroad. This instrument moved with the power-pack as the gateroad advanced, or retreated, so ensuring the measurements taken were at a constant strata age throughout.

The thermohygrograph required calibration prior to installation and when the recording was finished. The instrument was calibrated by using a hand held Assman psychrometer, measuring the dry bulb and the wet bulb temperatures. The wick attached to the wet bulb thermometer of the Assman psychrometer must be thoroughly wetted with distilled water. Since the the air condition measured by the thermohygrograph was in terms of dry bulb temperature and relative humidity, the dry bulb temperature and wet bulb temperature measured by the Assman psychrometer had to be converted to the corresponding dry bulb temperature and relative humidity of the air, by a psychrometric chart, for the calibration of the thermohygrograph.

After the surveys were completed, the thermohygrograph charts, with traces representing the temperature and relative humidity at various times, were digitised at HQTD. The digitised data was then loaded into the computer at the same establishment, and programmes VEN 105 and VEN 107 (HQTD) were programmed by Maneylaws (1988) of HQTD in order to convert the digitised data to temperature readings.

The stations, at which the thermohygrographs were located, at each site, were as follows:

(i) In the main drift, the stations were located at each end of the sectioned roadway.

(ii) In the conveyor roadway, three stations were located; one at each end and one in the middle of the roadway.

(iii) Six stations were located in the advance face working district at Wearmouth colliery. Station 1 was at the outbye of the maingate. Stations 2 and 3 were at the inbye of the maingate; station 2 just before the air duct of the local recirculation fan, and station 3 close to the face line. Stations 4 and 5 were at the inbye of the tailgate; station 4 close to the face line, and station 5 after the air duct of the recirculation fan. Station 6 was at the outbye of the tailgate.

(iv) Four stations were located in the retreat face working district at

Whitemoor colliery. Stations 1 and 2 were in the maingate; 1 at the outbye end and 2 at the inbye end, close to the face line. Stations 3 and 4 were in the tailgate; 3 at the inbye end, at a distance which was calculated from the time needed for the face to retreat backward, away from the face, and 4 at the outbye end.

Air velocity and roadway dimensions were measured at all sites. In addition to these measurements, the operating hours of the conveyor machinery, obtained from the Colliery Information System, were provided by the technical staff at HQTD. The Information Colliery System is a computer system which links the colliery and HQTD. The system is currently installed at modern collieries by British Coal, so that they can monitor the mining activity of underground workings.

CHAPTER EIGHT

DISCUSSION

A transient computer model incorporating the mathematical model developed for the calculation of the transient heat flow from strata (Cheung, 1989) and conveyed coal (Cheung and Rabia, 1989), the heat storage effect in structural steel (Maneylaws, 1988), and the empirical equations developed for estimating the heat from conveyor machinery (Browning et al, 1981), has been developed for predicting transient temperatures in an underground roadway. This model is presented in the form of a computer programme, which it is anticipated will be used to provide temperature predictions for future mine ventilation planning. In order to achieve this, it is essential to validate the computer programme using actual temperature data, before the programme is put into practice. Existing data supplied by British Coal HQTD was initially used for this purpose, and when satisfactory results were obtained using this data, actual data obtained from several temperature surveys at two collieries were examined.

Cheung (1988) developed a mathematical model to calculate the heat flow from strata in a mine roadway. Since the model only calculates the strata heat flow, existing data, which were only for roadways with no machinery, were supplied by British Coal to test the accuracy of the model by comparing the predicted temperature from the model with actual data. Satisfactory results from these tests were obtained by Cheung (1988).

Cheung and Rabia (1989) developed a mathematical model to calculate the heat flow from a continuous slab of coal on a conveyor. The technique used in this model is similar to that used by Cheung (1988), using Duhamel's Theorem. Satisfactory results were obtained from comparison of the predicted surface temperatures of coal with those predicted by Hermanns (1976) using a graphical method.

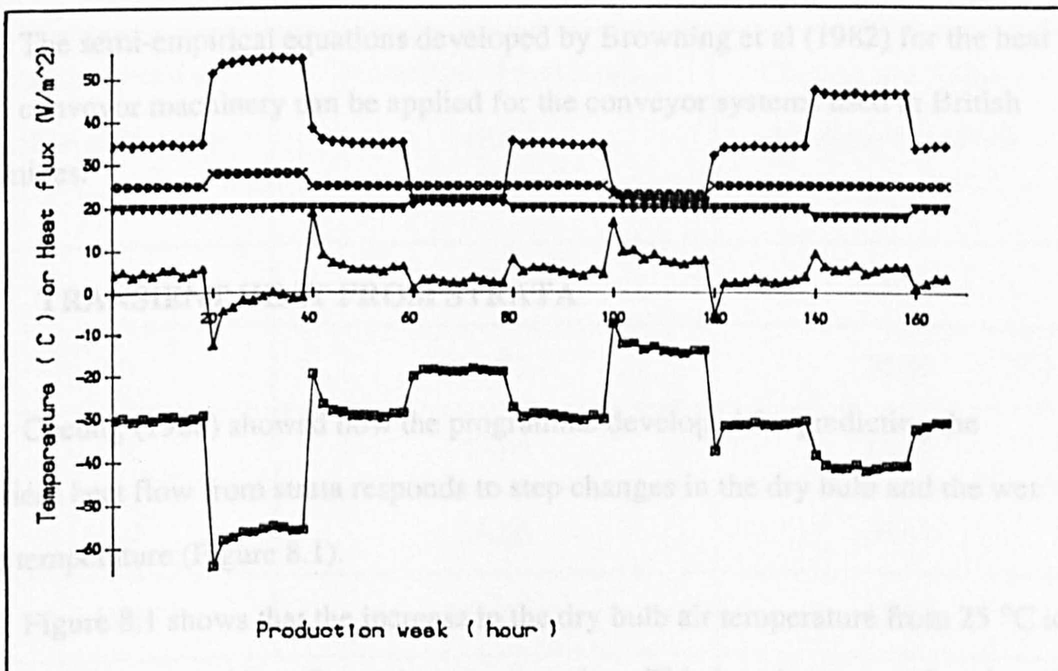


Figure 8.1 Illustration of the Strata Response to the Varying Heat Flux.

where
X dry bulb temperature (°C)
∇ wet bulb temperature (°C)
Δ Total heat flux (W/m²)
□ "dry" heat flux (W/m²)
◇ "wet" heat flux (W/m²)

Maneylaws (1988) developed a mathematical method based on the Lumped Capacity Method for heat storage in structural steel in an underground roadway. This is a very simplified method, in that it considers all the steel in the roadway as a whole mass of steel, for which the average heat transfer coefficient and average temperature are assumed. However, Maneylaws (1988) thought the method adequate for the calculation of the heat stored in, or emitted by, structural steel because the heat stored in structural steel is small compared to the heat stored in strata and conveyed coal.

The semi-empirical equations developed by Browning et al (1982) for the heat from conveyor machinery can be applied for the conveyor systems used in British coalmines.

8.1 TRANSIENT HEAT FROM STRATA

Cheung (1988) showed how the programme developed for predicting the transient heat flow from strata responds to step changes in the dry bulb and the wet bulb temperature (Figure 8.1).

Figure 8.1 shows that the increase in the dry bulb air temperature from 25 °C to 28 °C causes the total heat flux to become negative. This is to be expected as there will be a reversal of heat flow form the air to the surface layer of the strata because the air temperature of 28 °C is higher than the virgin strata temperature of 26.5 °C, at which the predictions are made. The reason for the increase in 'wet' heat at this point is that the 'dry' heat flowing into the strata accelerates the rate of evaporation of moisture from the strata. After a step change in the air temperature, it takes about 12 hours for the strata to respond to the constant air temperature and reach a steady state. This compares to the effect that heat flow from the waste (Browning, 1980) has on the air temperature at the face. This temperature will take about 12-15 hours to become stable after the production ceases. A decrease in the dry bulb temperature of the air from 28 °C to 25 °C will cause dry heat to flow out from the strata and consequently, the 'wet' heat due to the evaporation of moisture from the strata will decrease. An increase in the wet bulb temperature from 20 °C to 22 °C will cause a decrease in 'wet' heat flowing from the strata, and vice versa, because the rate of evaporation of moisture depends on the difference between the vapour pressure of the air and the saturation pressure at the surface temperature. Hence, less 'dry' heat is flowing into the strata when the wet bulb temperature of the air is increased, and vice versa.

Distance from the inbye of the gate (m)	Hermanns' Predictions (1976) (°C)	Cheung and Rabia's Predictions (1988) (°C)
0	37.90	37.90
40	30.05	29.26
79	27.98	27.41
119	26.66	26.31
158	25.67	25.54
198	24.89	24.97
237	24.24	24.52
277	23.68	24.16
290	23.51	23.85

Table 8.1 Comparison of the Surface Temperature Predictions Made by Hermanns (1976) and by Cheung and Rabia (1988).

8.2 TRANSIENT HEAT FLOW FROM CONVEYED COAL

Cheung and Rabia (1989) developed a mathematical model for calculating the surface temperature of a continuous slab of coal. The heat flux from the slab can then be calculated. The assumption made by the mathematical model is that the mixing of coal does not occur. Otherwise, there will be considerable effects resulting from the porosity and the movement of the coal. Air flowing into the pores of the coal particles will enhance the rate of heat pick-up, and the movement of the coal will cause mixing of coal particles of varying temperature. Consequently, the thermal properties of the coal would be affected.

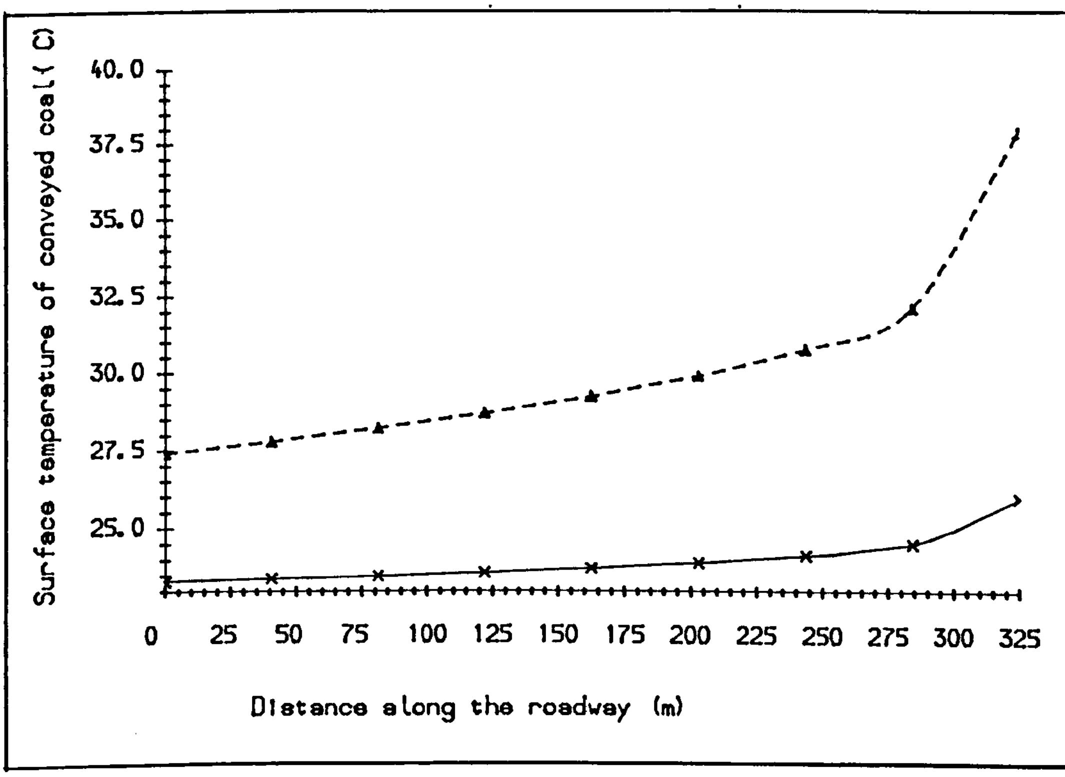


Figure 8.2 Comparison of the Predicted Surface Temperature of Coal.

where X Wearmouth Colliery

Δ Tilmanstone Colliery

Cheung and Rabia (1988) achieved good agreements (Table 8.1) between their predicted surface temperature and those of Hermanns (1976). Hermanns' predictions (1976) are based on a graphical technique (Voss, 1965) for the calculation of the surface temperature of a continuous slab of conveyed coal. In addition to these comparisons of predicted surface temperatures, Cheung and Rabia (1988) produced surface temperature predictions (Figure 8.2) by making certain assumptions about the input data for the conveyed coal in Wearmouth and Tilmanstone Collieries. Then the heat flux from the conveyed coal was predicted (Figure 8.3). The conclusion drawn by Cheung and Rabia (1989) for the predicted heat flux, for Tilmanstone Colliery (Figure 8.3), is that it will cause an increase of 1.3 °C in the dry bulb temperature and an increase of 4.3 °C in the wet bulb temperature, of the ventilation air.

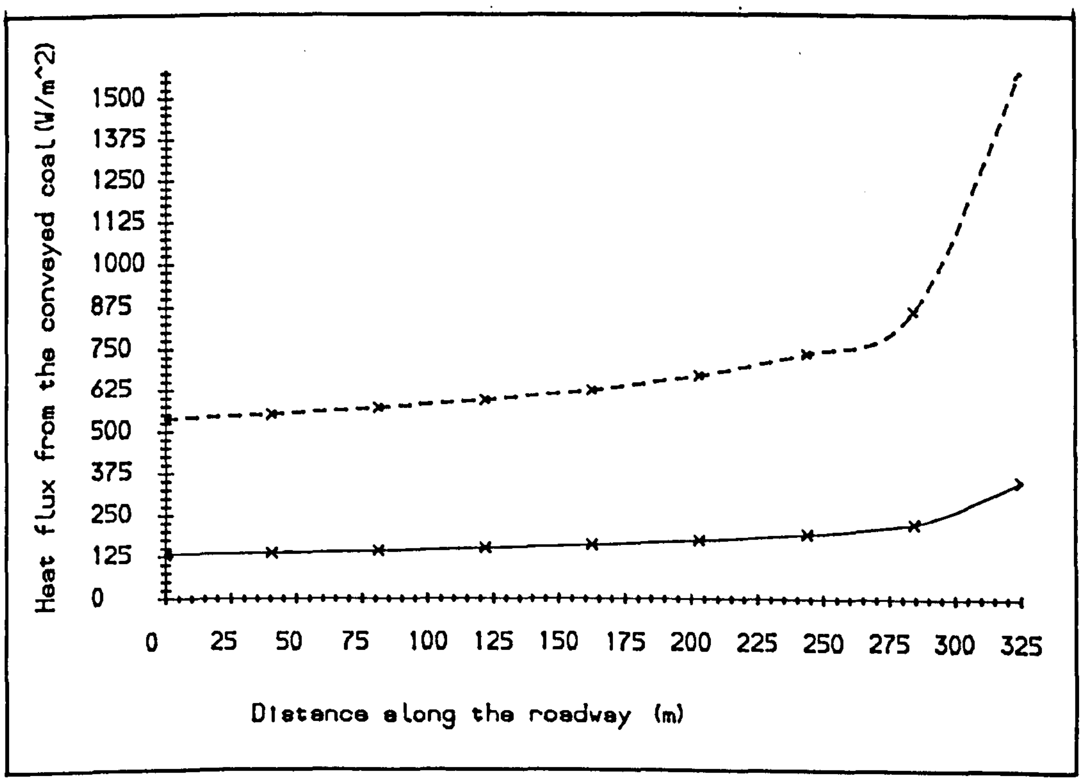


Figure 8.3 Comparison of the Predicted Heat Flux of Coal

where X Wearmouth Colliery

>I Tilmanstone Colliery

8.3 SITE MEASUREMENTS

Continuous measurements of air temperature and humidity may be made by a thermohygrograph. Satisfactory measurements were achieved at all three sites at Wearmouth Colliery. In the case of the measurements made at Whitemoor Colliery, the instrument failed to record air temperature and humidity for the first week. The thermohygrograph is a very sensitive instrument and when it is installed at a station the instrument must be secured properly to ensure that the recording pen contacts the thermohygrograph chart. Any slight movements of the instrument can cause the pen to move away from the chart and no recording will be made. It is probable that data was lost at Whitemoor Colliery due to poor pen to chart contact.

When a thermohygrograph is installed at the inbye end of a gateroad, it is important, to avoid installing the instrument to close to machinery, and to make sure the bracket, upon which the instrument is clamped, is free from vibration. Any vibration of the instrument will cause inaccurate measurement of air temperature and humidity. If the thermohygrograph is close to machinery, the heat from the machinery will cause increases in the air temperature and humidity, due to heat radiation. This will be recorded by the instrument.

In addition to the measurement of the air temperature and humidity, air velocity and the dimension of the roadway were measured.

Information on the operating hours of the conveyor machinery at Whitemoor Colliery was obtained from the Colliery Information System (CIS). Since the conveyor operates intermittently and the information is given in minutes, the operating hours of the conveyor are approximated to whole hours. If the conveyor operates more than sixty minutes within a period of two hours, the conveyor is said to be operated for two hours. However, since there is no information on the operating hours for the conveyor machinery at Wearmouth Colliery, the conveyor is assumed to be operated continuously over the production shifts during a week.

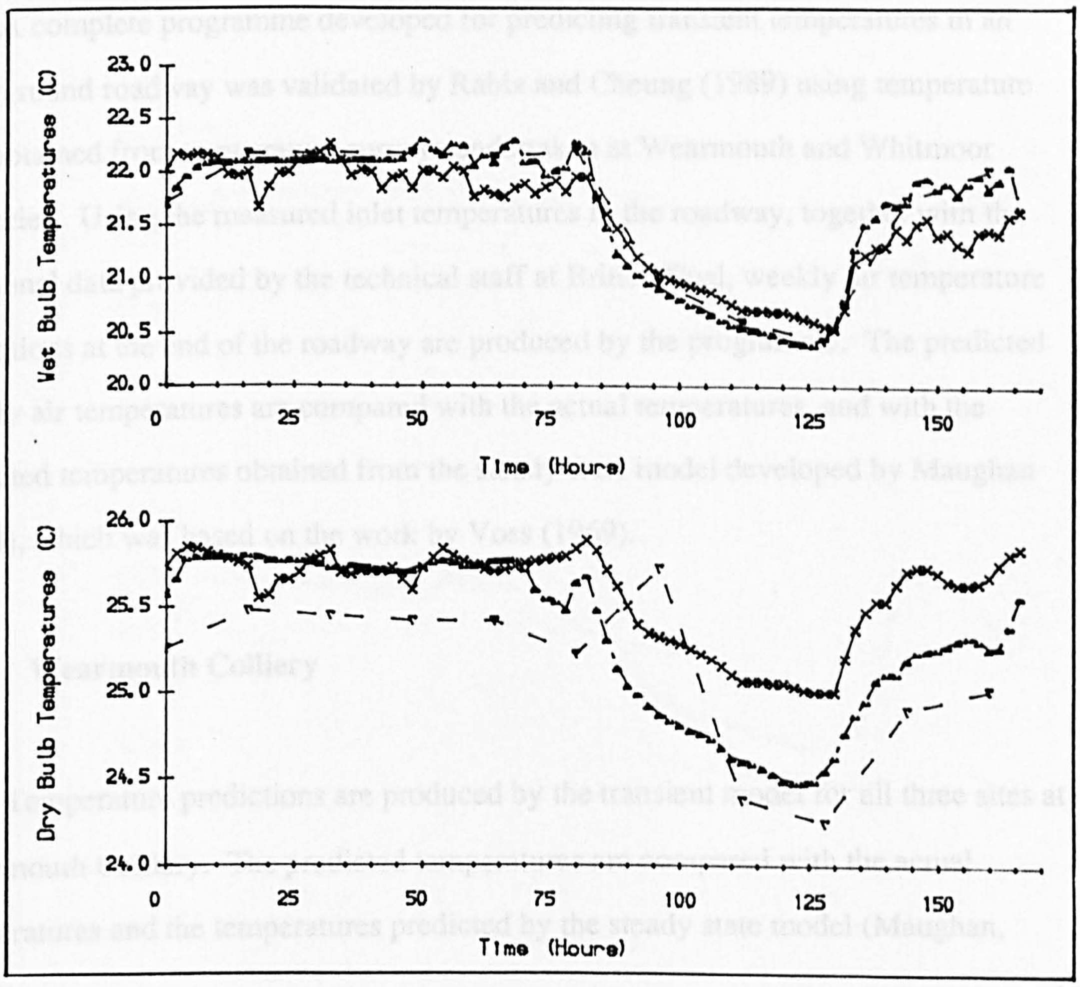


Figure 8.4 Comparison of the Predicted and the Actual Temperatures at the End of the Sectioned Main Drift.

where X actual temperature (°C)

Δ predicted temperature by the transient model (°C)

∇ predicted temperature by the steady state model (Maughan, 1988) (°C)

8.4 TEMPERATURE CORRELATIONS

A complete programme developed for predicting transient temperatures in an underground roadway was validated by Rabia and Cheung (1989) using temperature data obtained from temperature surveys undertaken at Wearmouth and Whitmoor Collieries. Using the measured inlet temperatures in the roadway, together with the additional data provided by the technical staff at British Coal, weekly air temperature predictions at the end of the roadway are produced by the programme. The predicted weekly air temperatures are compared with the actual temperatures, and with the predicted temperatures obtained from the steady state model developed by Maughan (1988), which was based on the work by Voss (1969).

8.4.1 Wearmouth Colliery

Temperature predictions are produced by the transient model for all three sites at Wearmouth Colliery. The predicted temperatures are compared with the actual temperatures and the temperatures predicted by the steady state model (Maughan, 1988).

8.4.1.1 Main drift

Heat flow in the drift comes from the strata only . Although locomotives and manriders occasionally pass through, the heat emitted by diesel engines is negligible. The predictions made by the transient and the steady state models (Figure 8.4) agree qualitatively. However, the transient temperature predictions show a better agreement with the actual measurements than do those produced from the steady state model.

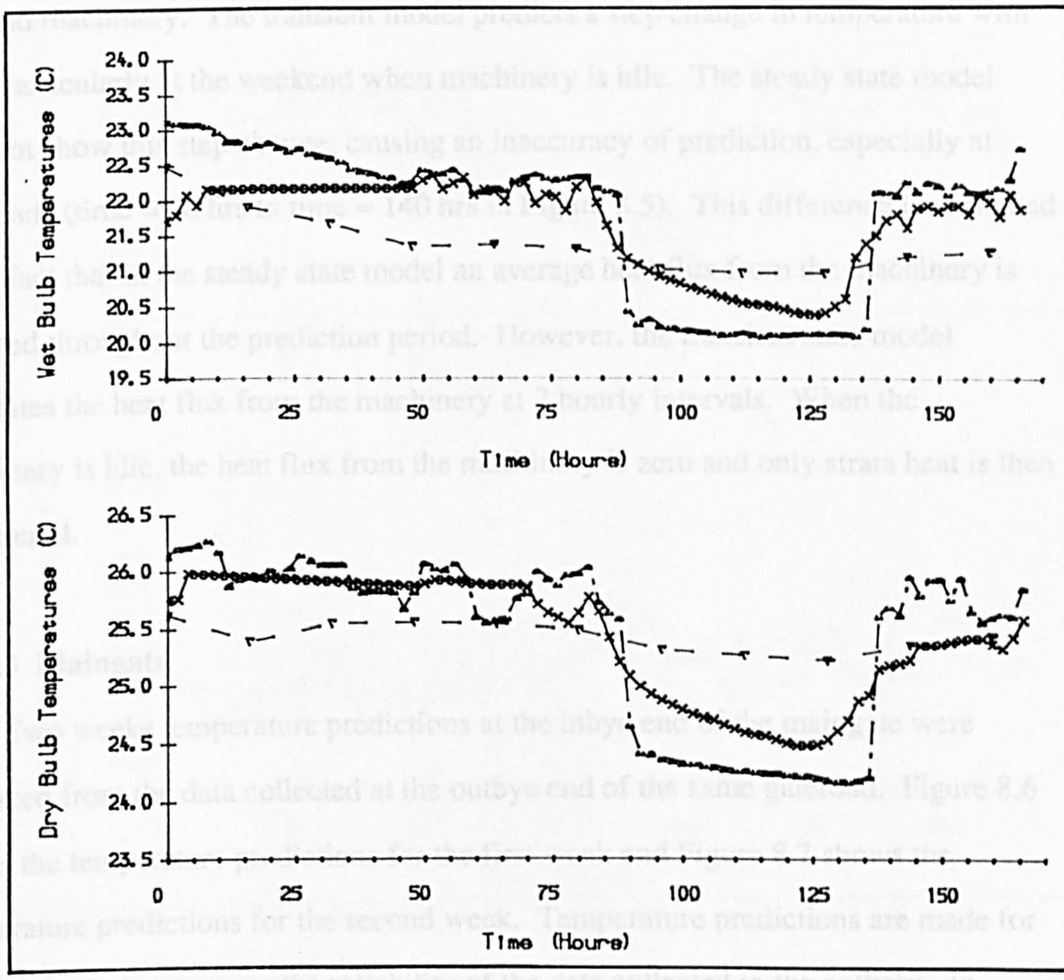


Figure 8.5 Comparison of the Predicted and the Actual Temperatures at the End of the Sectioned Conveyor Roadway.

where X actual temperature (°C)

Δ predicted temperature by the transient model (°C)

∇ predicted temperature by the steady state model (Maughan, 1988) (°C)

8.4.1.2 Conveyor roadway

The sources of heat in the conveyor roadway are : heat from strata, conveyed coal and machinery. The transient model predicts a step change in temperature with time, particularly at the weekend when machinery is idle. The steady state model does not show this step change, causing an inaccuracy of prediction, especially at weekends (time = 90 hrs to time = 140 hrs in Figure 8.5). This difference is attributed to the fact that in the steady state model an average heat flux from the machinery is assumed throughout the prediction period. However, the transient state model calculates the heat flux from the machinery at 2 hourly intervals. When the machinery is idle, the heat flux from the machinery is zero and only strata heat is then considered.

8.4.1.3 Maingate

Two weeks temperature predictions at the inbye end of the maingate were produced from the data collected at the outbye end of the same gateroad. Figure 8.6 shows the temperature predictions for the first week and Figure 8.7 shows the temperature predictions for the second week. Temperature predictions are made for two weeks to demonstrate the reliability of the data collected in the colliery. In addition, since there was a change in the ventilation conditions (i.e. air temperature at the outbye end of the maingate increased by 3 to 4 degrees C) at 60 hours in the first week, it is possible to see how the transient model responds to temperature variations.

The predicted dry bulb temperature from the steady state programme (Figures 8.6 and 8.7) is up to 3 °C higher than the actual temperature. However, the predicted wet bulb temperature is in reasonable agreement with measured values. The transient temperature predictions show better agreement with actual temperatures, for both the dry and wet bulb temperatures, than do those produced by Maughan's (1988) steady-state model.

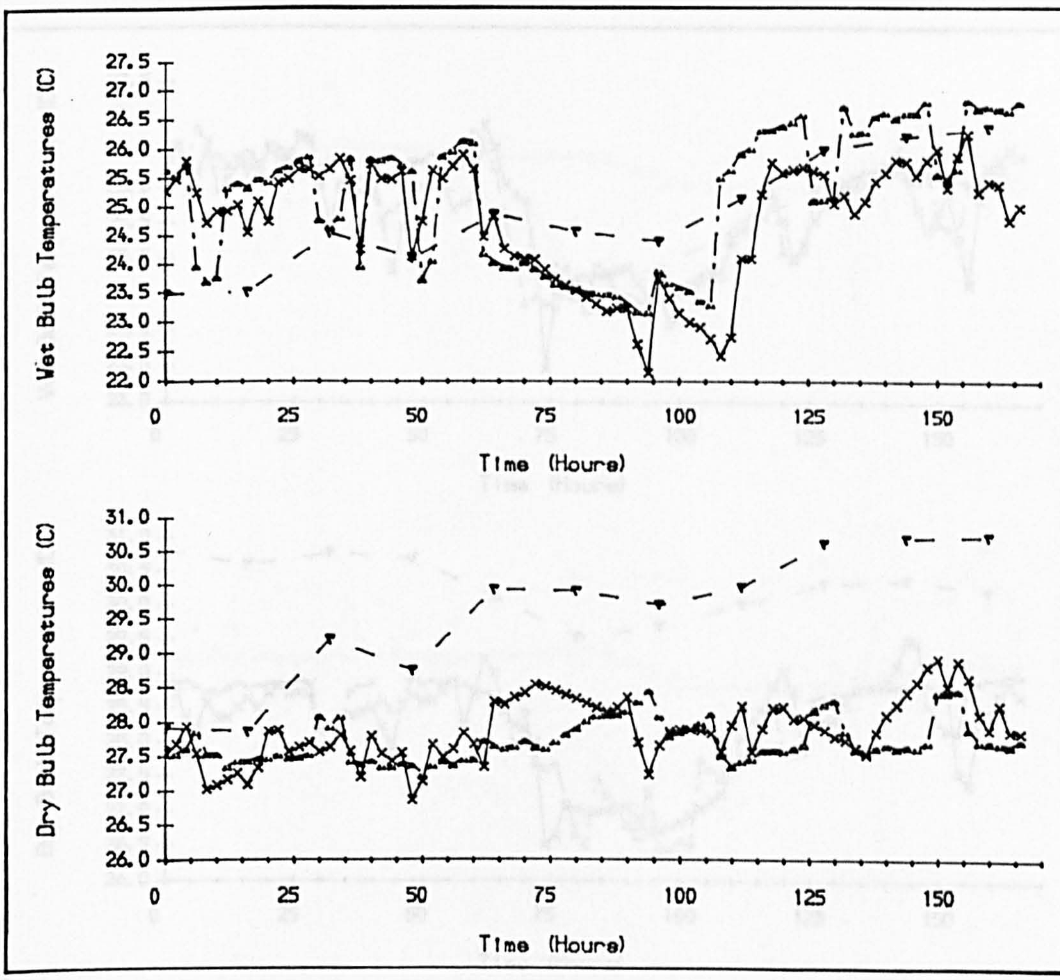


Figure 8.6 Comparison of the Predicted and the Actual Temperatures at the Inbye End of the Maingate of an Advancing Face at Wearmouth Colliery for the First Week.

where X actual temperature (°C)

Δ predicted temperature by the transient model (°C)

∇ predicted temperature by the steady state model (Maughan, 1988) (°C)

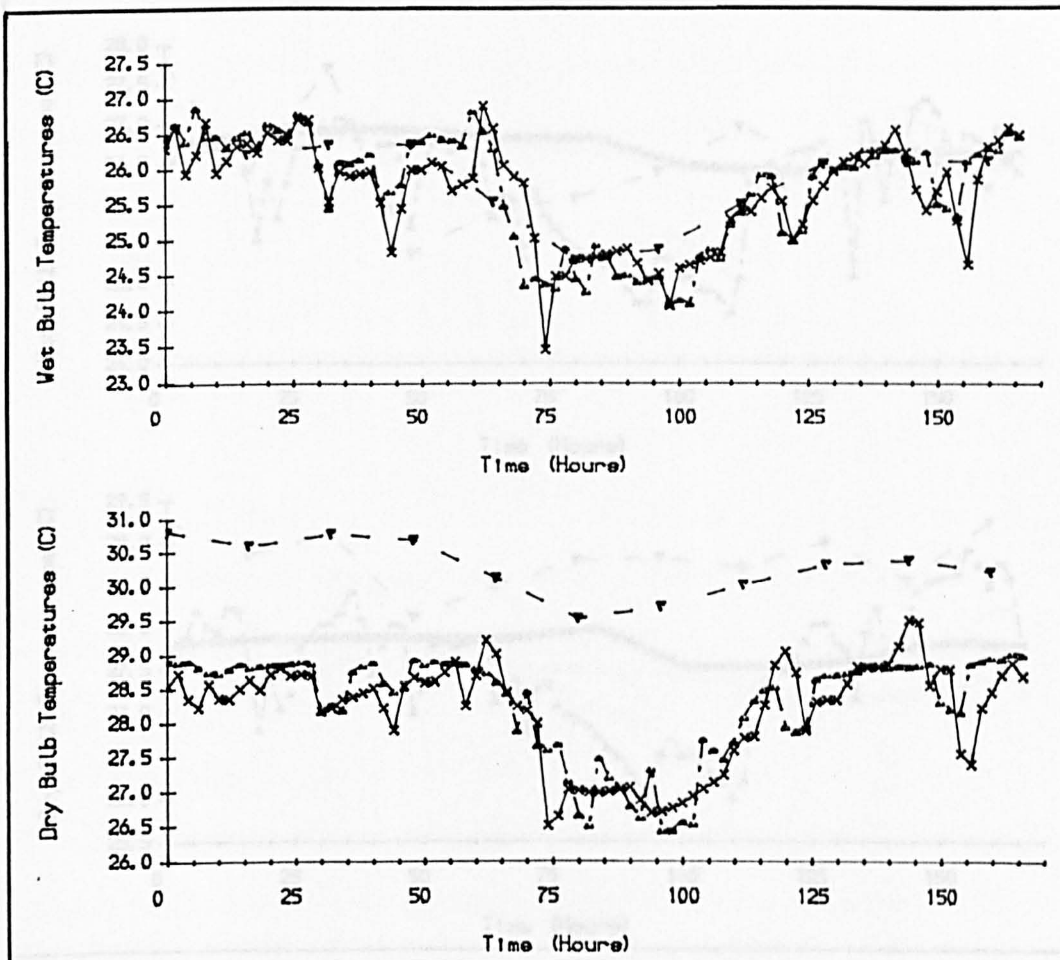


Figure 8.7 Comparison of the Predicted and the Actual Temperatures at the Inbye End of the Maingate of an Advancing Face at Wearmouth Colliery for the Second Week.

where X actual temperature (°C)

Δ predicted temperature by the transient model (°C)

∇ predicted temperature by the steady state model (Maughan, 1988) (°C)

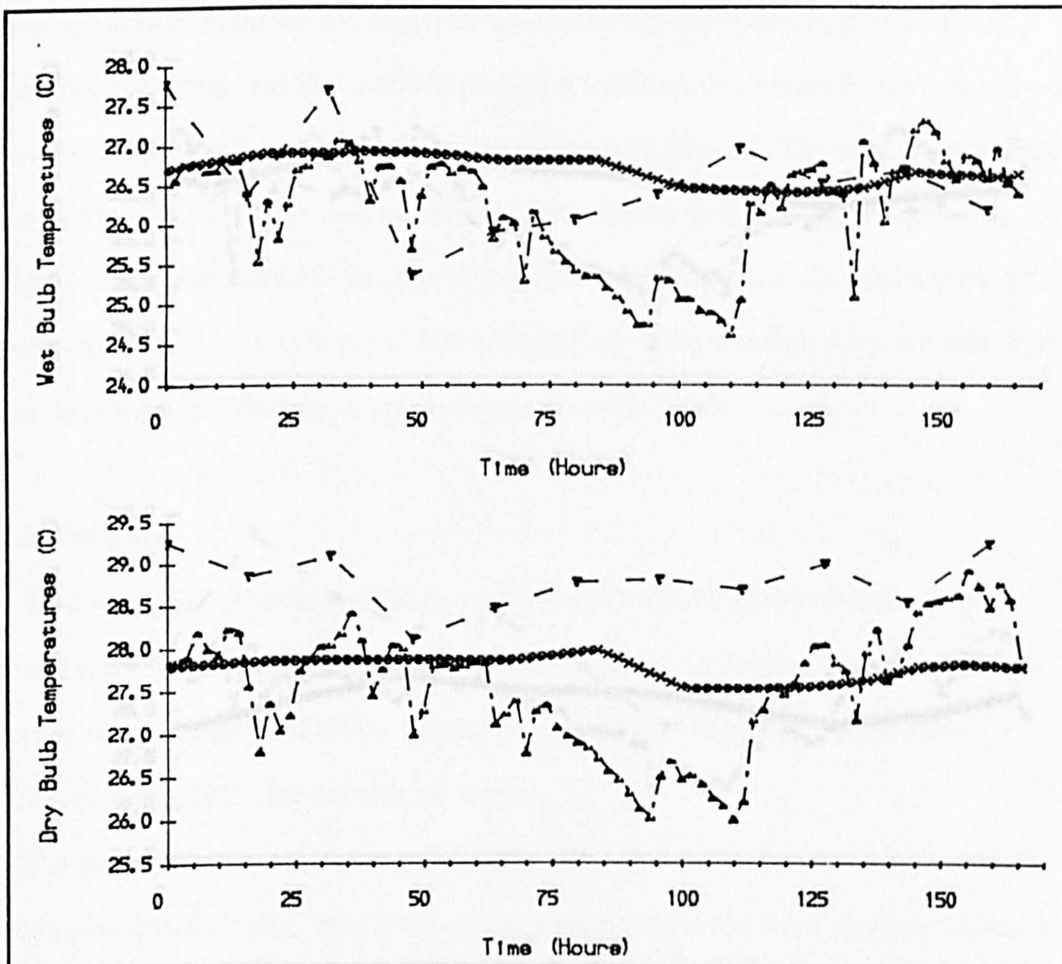


Figure 8.8 Comparison of the Predicted and the Actual Temperatures at the Outbye End of the Tailgate of an Advancing Face at Wearmouth Colliery for the First Week.

where X actual temperature (°C)

Δ predicted temperature by the transient model (°C)

∇ predicted temperature by the steady state model (Maughan, 1988) (°C)

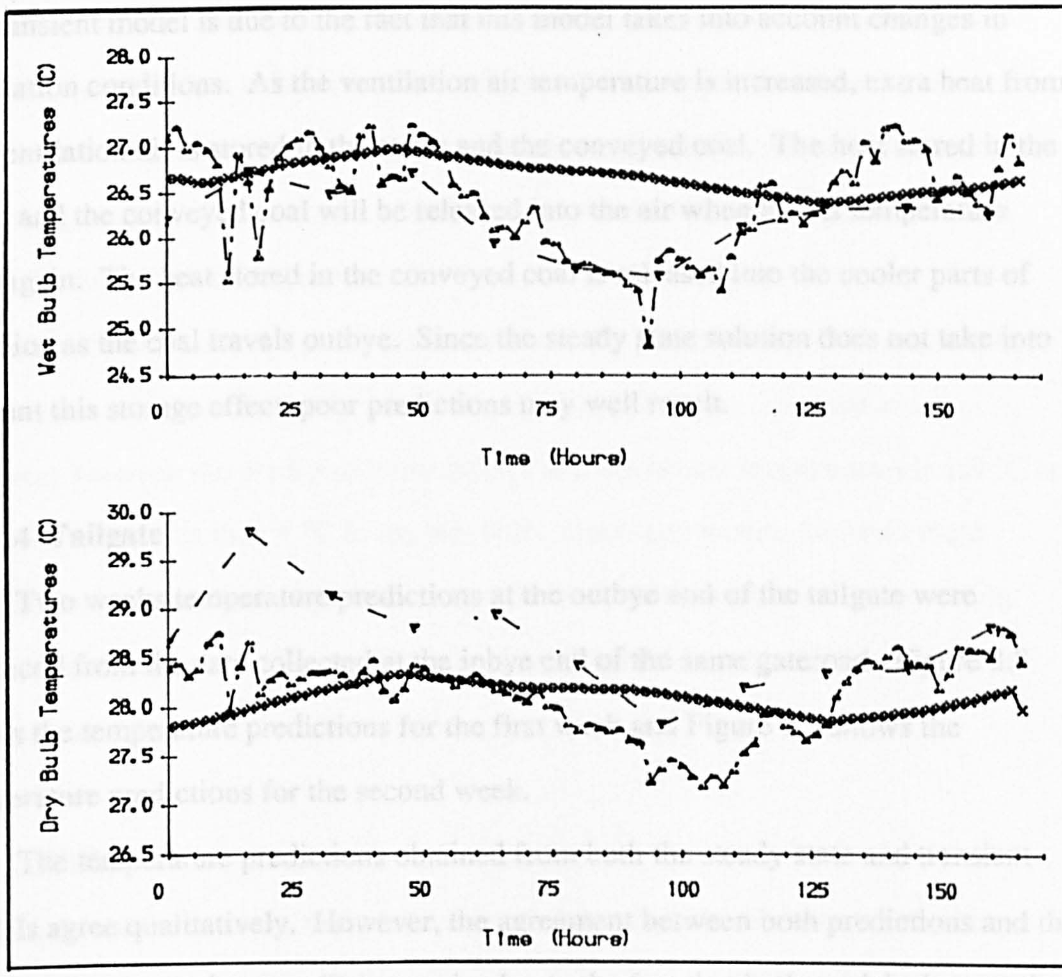


Figure 8.9 Comparison of the Predicted and the Actual Temperatures at the Outbye End of the Tailgate of an Advancing Face at Wearmouth Colliery for the Second Week.

where
- X actual temperature (°C)
- Δ predicted temperature by the transient model (°C)
- ∇ predicted temperature by the steady state model (Maughan, 1988) (°C)

The good agreement between the measured temperatures and those predicted by the transient model is due to the fact that this model takes into account changes in ventilation conditions. As the ventilation air temperature is increased, extra heat from the ventilation air is stored in the strata and the conveyed coal. The heat stored in the strata and the conveyed coal will be released into the air when the air temperature falls again. The heat stored in the conveyed coal is released into the cooler parts of the mine as the coal travels outbye. Since the steady state solution does not take into account this storage effect, poor predictions may well result.

8.4.1.4 Tailgate

Two weeks temperature predictions at the outbye end of the tailgate were produced from the data collected at the inbye end of the same gateroad. Figure 8.8 shows the temperature predictions for the first week and Figure 8.9 shows the temperature predictions for the second week.

The temperature predictions obtained from both the steady state and transient models agree qualitatively. However, the agreement between both predictions and the actual temperatures is poor. This may be due to the fact that both models do not take into account the extra heat source, heat from the waste, which dampens the air temperatures at the outbye of the tailgate.

8.4.2 Whitemoor Colliery

Temperature predictions are made at the inbye end of the maingate and at the outbye end of the tailgate from the data collected at the outbye end of the maingate and at the inbye end of the tailgate, respectively, for a retreating face at Whitemoor Colliery. Since the ventilated age of the gateroad in a retreating face is higher than that of an advance face, the age is assumed to be constant over the length of the gateroad.

8.4.2.1 Maingate

Figure 8.10 shows the temperature predictions made at the inbye end of the maingate from the data collected at the outbye end of the same gateroad for the second week. There are no temperature predictions for the first week because the thermohygrograph at the outbye end failed to record the temperature and humidity during the first week of the survey.

It can be seen from Figure 8.10, in that both the predicted dry bulb and wet bulb temperatures match very closely with the actual temperatures. The maximum difference between the predicted temperatures and the actual temperatures is 1.5 °C in the dry bulb and less than 1 °C in the wet bulb. Good agreements between these temperatures may be attributed to the accuracy in determining the actual operating hours of the conveyor machinery from the data obtained from the Colliery Information System.

8.4.2.2 Tailgate

Figure 8.11 shows the temperature predictions made at the outbye end of the tailgate from the data collected at the inbye end of the same gate road for the first week, and similarly, Figure 8.12 shows the temperature predictions made for the second week.

Both the predicted dry bulb and wet bulb temperatures in Figure 8.11 match the actual temperature qualitatively. The difference between the predicted temperatures and the actual temperatures is 3.5 °C in the dry bulb and 5.0 °C in the wet bulb. These differences are to be expected because similar differences between the actual temperatures at the inbye end, and at the outbye end, of the tailgate are recorded. There is no explanation for these differences, especially for the air temperatures at the inbye end, where both the dry bulb and the wet bulb, at most points, are higher than the temperatures at the outbye end (Figure 8.13). This can only be possible if the air was being cooled as it travelled outbye. In this case, no cooling equipment was installed in the tailgate. Thus, there is some doubt about the accuracy of the data collected in the first week.

The predicted temperature, for the first 100 hours, shown in Figure 8.12 matches very well with the actual temperature. After the 100 th hour, constant predicted temperatures are obtained. This is because only the first 100 hours of the air temperature and humidity have been recorded in the second week, and in order to make the predictions possible, the average temperature of the first 100 hours was assumed to be the input temperature for the rest of the week.

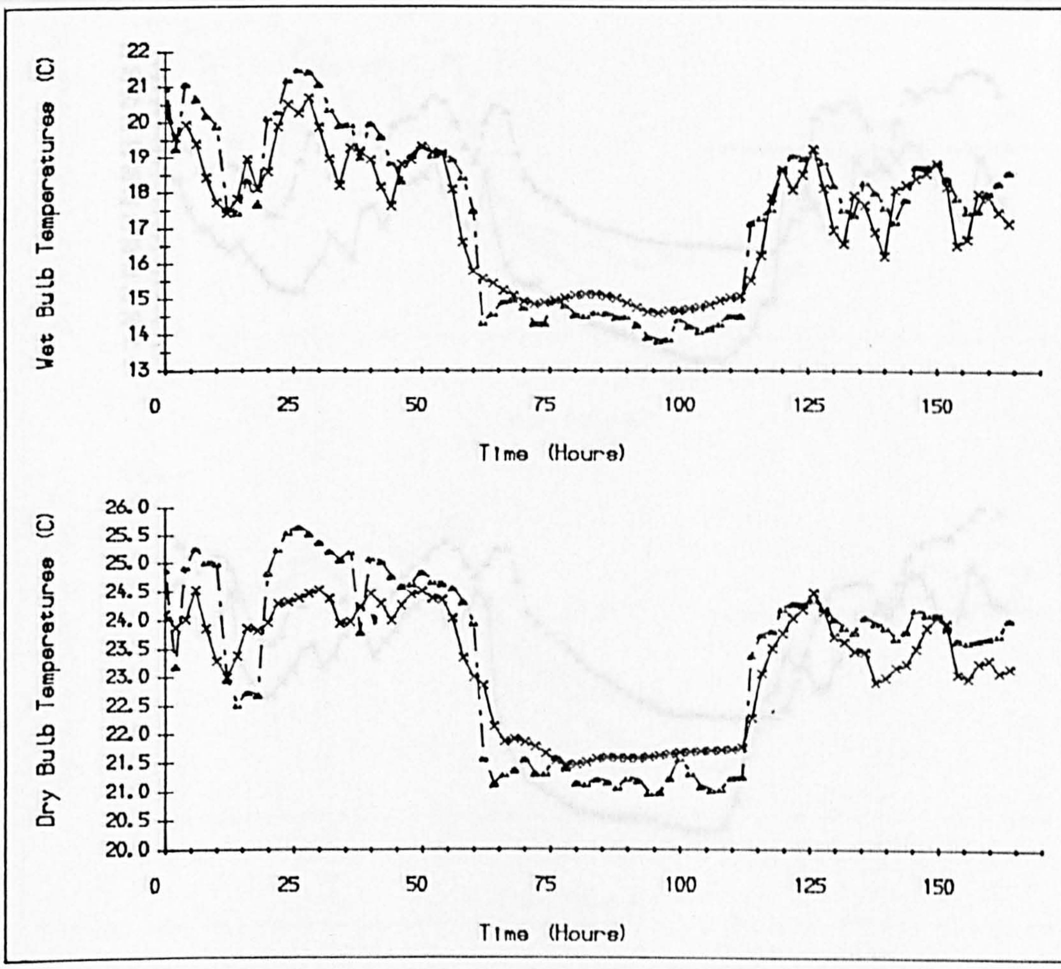


Figure 8.10 Comparison of the Predicted and the Actual Temperatures at the Inbye End of the Maingate of a Retreating Face at Whitemoor Colliery for the Second Week.

where X actual temperature (°C)

Δ predicted temperature by the transient model (°C)

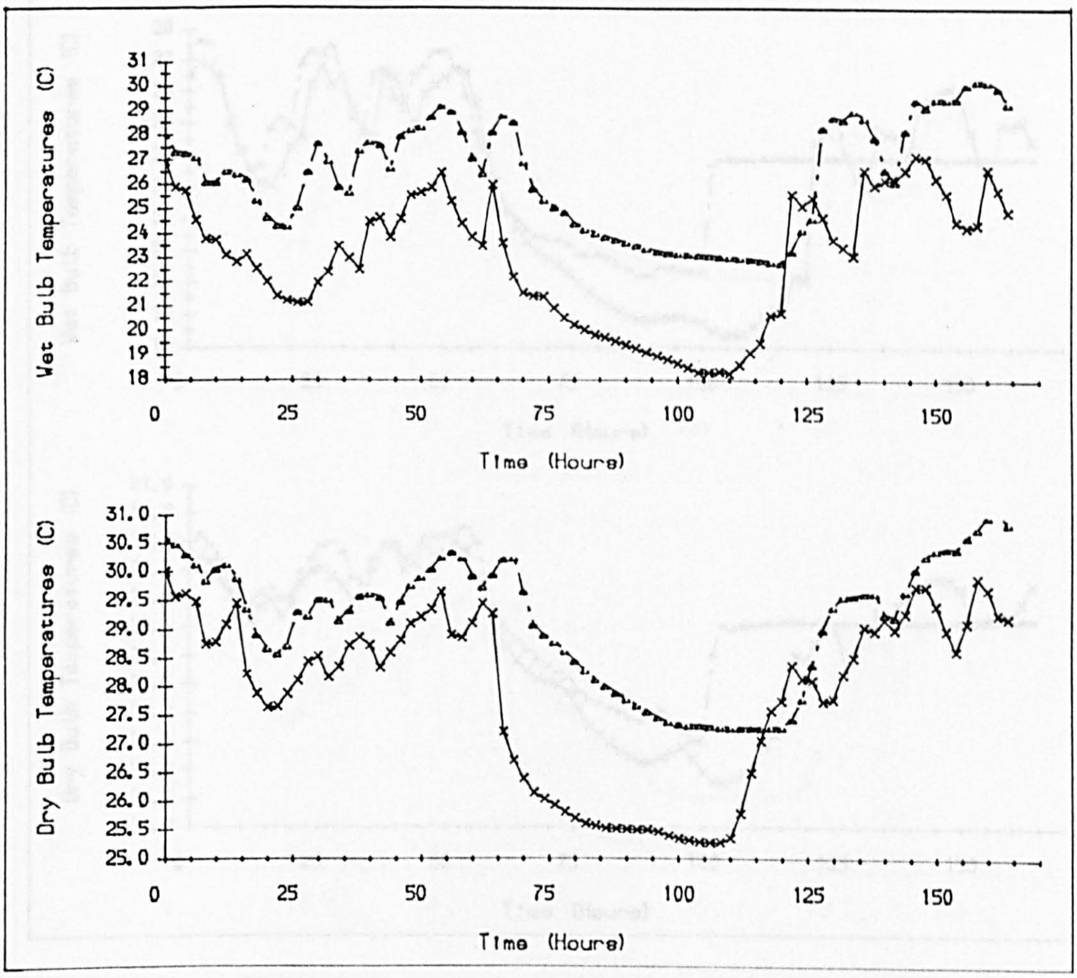


Figure 8.11 Comparison of the Predicted and the Actual Temperatures at the Outbye End of the Tailgate of a Retreating Face at Whitemoor Colliery for the First Week.

where X actual temperature (°C)

Δ predicted temperature by the transient model (°C)

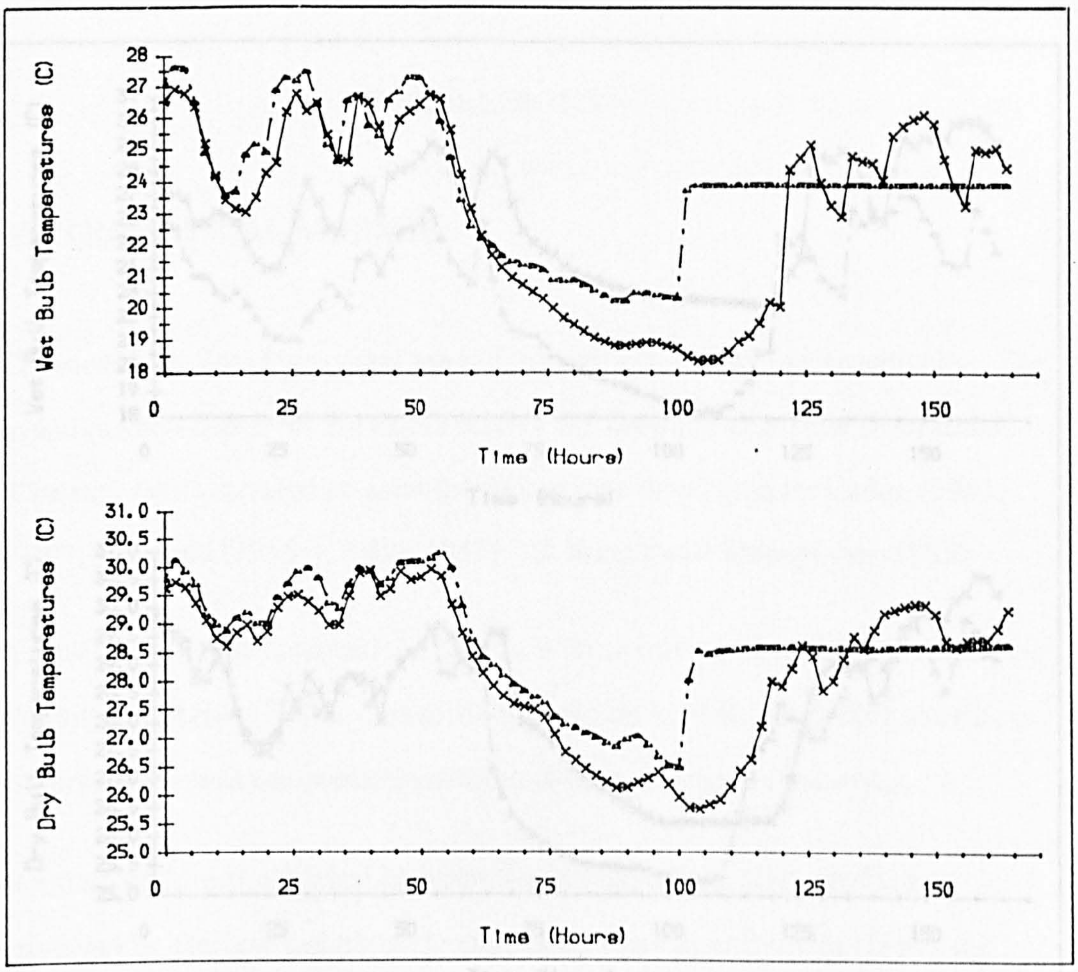


Figure 8.12 Comparison of the Predicted and the Actual Temperatures at the Outbye End of the Tailgate of a Retreating Face at Whitemoor Colliery for the Second Week.

where X actual temperature (°C)

Δ predicted temperature by the transient model (°C)

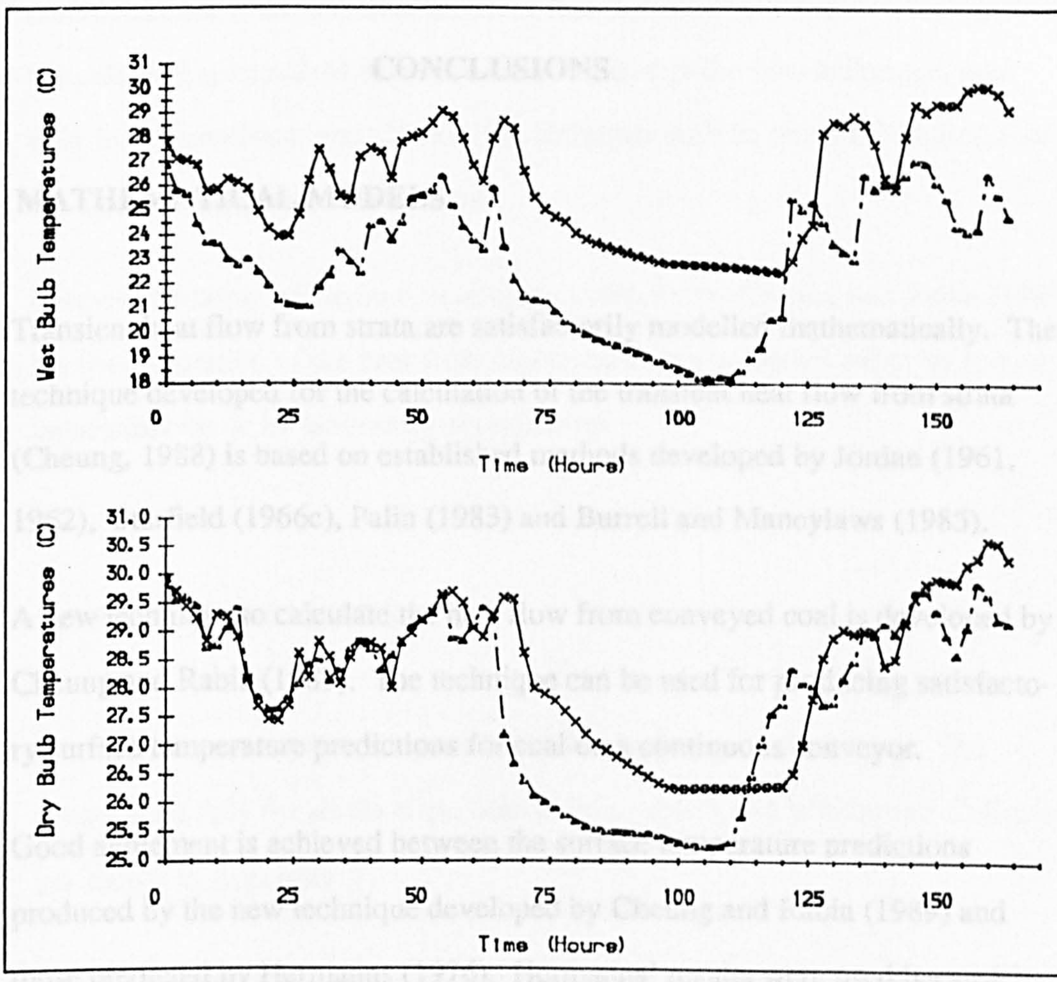


Figure 8.13 The Actual Temperature at the Inbye End and at the Outbye End of the Tailgate of a Retreating Face at Whitemoor Colliery for the First Week.

where X temperatures at the inbye end (°C)

Δ temperatures at the outbye end (°C)

CHAPTER NINE

CONCLUSIONS

9.1 MATHEMATICAL MODELS

1.0 Transient heat flow from strata are satisfactorily modelled mathematically. The technique developed for the calculation of the transient heat flow from strata (Cheung, 1988) is based on established methods developed by Jordan (1961, 1962), Starfield (1966c), Palin (1983) and Burrell and Maneylaws (1985).

2.0 A new technique to calculate the heat flow from conveyed coal is developed by Cheung and Rabia (1989). The technique can be used for producing satisfactory surface temperature predictions for coal on a continuous conveyor.

3.0 Good agreement is achieved between the surface temperature predictions produced by the new technique developed by Cheung and Rabia (1989) and those predicted by Hermanns (1976). Hermanns' results were used because they are the only results which are available for validating the new technique.

4.0 Since the new approach is based on a sound mathematical technique, taking into account the varying temperature over the conveyed coal, and the development of a computer programme is less complicated, it is considered to be superior and inherently more accurate than Hermanns Graphical Method (1976).

5.0 An advantage in adding the new technique for calculating heat flow from conveyed coal to the transient model is that the same subroutines developed for the calculating heat flow from strata can be used in the new technique, with only minor modifications. Hence, the computer code in terms of the length of the transient programme is reduced.

6.0 Further validation of the new technique developed by Cheung and Rabia (1989) for the calculation of the heat from conveyed coal are needed either by in-situ measurements or by laboratory experiments.

9.2 SITE MEASUREMENTS

1.0 Site measurements of air temperature and humidity are satisfactory. The temperature data for all the sites, both at Wearmouth and Whitemoor Collieries are shown in Appendix V.

2.0 The information about the operation of the conveyor machinery, provided by the CIS, is very useful for determining the operating hours of the conveyor within a week. When such information is not available, assumptions of continuous operation of the conveyor during a production shift, and of machinery being idle during a weekend break, are acceptable.

9.3 COMPUTER MODEL

1.0 A transient model to produce transient temperature predictions for an underground roadway is developed, taking account of the heat from strata, conveyed coal, machinery, and the heat stored in structural steel. In addition, the model does not assume a constant temperature over the ventilated age of the roadway.

9.4 TEMPERATURE PREDICTIONS

1.0 The temperature predictions made for all the sites at Wearmouth and Whitemoor Collieries have not taken account of any heat stored in the structural steel because, (i), the heat from the structural steel provides little contribution to the change of the air temperature compared with the heat from the major heat sources in a roadway, and (ii), it is difficult to estimate the surface area of steel in a roadway.

2.0 If the subroutine for the heat stored in, or emitted by, the structural steel is omitted when the predictions are made, the computation time is reduced without significantly affecting the accuracy of the predictions.

3.0 Temperature predictions can be produced either by the steady state model (Maughan, 1988) or by the transient model.

4.0 Advantages in using the steady state model for predicting temperatures are, (i), the model is simple, (ii), the programme can be run far faster on a micro-computer than can the transient model's programme, and (iii), little input data are required.

5.0 The steady state model is incapable of producing reasonably accurate temperature predictions when variations of air temperature take place. The temperature predictions produced by the transient model for all the sites at Wearmouth Colliery give a better match with the actual temperatures than do those predicted by the steady state model, especially when variations in the air temperatures of up to several degrees C are encountered (see 6.0 below).

6.0 In general, the steady state and transient, models produce temperature predictions higher and lower than the actual temperatures, respectively.

CHAPTER TEN

FUTURE WORK

1.0 To date, the transient model has been tested with limited data, all of which were obtained from temperature surveys undertaken at Wearmouth and Whitemoor Collieries. If the model is to be put into practice, more underground data are needed in order to validate the reliability and accuracy of the transient and steady state models.

2.0 Investigations of air leakage through the waste and the packing at the inbye end of the tailgate of an advancing face are needed. This will provide information for improving the transient model.

3.0 An electronic instrument capable of continuously measuring air temperature and humidity underground should be devised for future temperature surveys. The instrument should be protected against vibration. With more accurate underground data, the model could be subjected to a more rigorous test.

4.0 A transient model for a production face should be developed. Such a model should be developed in such way that, it can combine with the transient model developed herein for predicting air temperatures in underground roadways. The combined models can then produce temperature predictions for a whole district, which includes a maingate, a face and a tailgate.

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APPENDIX I

A TRANSIENT COMPUTER PROGRAM

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C Program CLIMATE.for is used to calculate the temperature predictions from
C heat sources in underground mines. The prediction of the transient
C temperatures is made. The heat sources include the heat from strata, heat
C from machinery, heat from conveyed coal and heat from the conveyor
C machine.
C
   CHARACTER*16 FNAME2
   DIMENSION IDATA(7), RDATA(12), CDATA(14), VDATA(0:83)
   DIMENSION SETA(0:83), TTDRY(0:83,0:10), TTWET(0:83,0:10)
   DIMENSION PMACH(0:83,10), NCONV(0:83), NPOWER(0:83),ETA(0:460)
   DIMENSION FI(0:460),FIMEAN(460),DRY1(0:460),WET1(0:460)
   DIMENSION RAYAGE(0:10),RAYVST(0:10),T1(0:460),T2(0:460)
   DIMENSION QSW1(0:83),QSW2(0:83),QST1(0:83),QST2(0:83)
   DIMENSION QP(0:83),DRY2(0:460),WET2(0:460),QCOALW(0:83,10)
   DIMENSION TEMDRY(0:83),TEMWET(0:83),QCOALT(0:83,10)
   DIMENSION QSTLT(0:83,10),QSTLW(0:83,10),STDATA(5),VAPOUR(0:83,10)
   DIMENSION RECFTR(0:83),RECDRY(0:83),RECWET(0:83),VDSAVE(0:83)
   DIMENSION TON(10)
C
   REAL RADIUS
C
   COMMON/RINPUT/ IDATA, RDATA, CDATA, TTDRY, TTWET, PMACH,
  +         VDATA,SETA,NCONV,NPOWER,STDATA,FNAME2,
  +         RECFTR,RECDRY,RECWET,TON
   COMMON/STRATA/SRAD,SCONV,CPROCK,RHOROC,GRA,PI
   COMMON/AIRCON/P,RD,CPAIR
   COMMON/COLCON/CFREE,CRAD,CCONV
   COMMON/STLCON/STLCP,STLRAD
C
   SVP(T)=613.6*EXP(T*(0.0725526-T*(0.000289154-T*0.000000818529)))
   PRE(P,D,W)=SVP(W)-0.000666*P*(D-W)
   DENS(P,D,W)=3.48*(P-0.378*PRE(P,D,W))/(1000*(273+D))
   RV(T)=2497000-2250*T
C
   CALL TITLE(6)
C
   CALL INPUT (PI,RADIUS,SCONV,IFCOAL)
   CALL INIT(IDATA(1),IDATA(2),RDATA,RAYAGE,RAYVST)
C
C To take account of the heat from conveyed coal and the heat storage by steelwork.
C
   IF (IFCOAL.EQ.1.OR.STDATA(4).EQ.1.0) THEN
     LOOP=2
   ELSE
     LOOP=1
   ENDIF
C
C This outer if loop is to combine the heat from strata and the heat from
C conveyed coal.
C
   ISAVE=1
C
   DO 100 NLOOP=1,LOOP
C
C To initialise zero array for heat from conveyed coal and heat stored.
C
     IF (NLOOP.EQ.1) THEN
       DO 5 I=0,83
         DO 5 J=1,IDATA(2)
```

```
          QCOALT(I,J)=0.0
          QCOALW(I,J)=0.0
          QSTLT(I,J)=0.0
          QSTLW(I,J)=0.0
5       CONTINUE
        WRITE(6,6)
6       FORMAT(/,3X,' Heat flow from strata and Machinery only :')
      ELSE
        WRITE(6,8)
8       FORMAT(/,3X,' Heat fow from all sources :')
      ENDIF
C
    CALL SAGE(IDATA(4),RDATA(11),CPROCK,RHOROC,RADIUS,RAYAGE(0),
   +         FI,FIMEAN,NTERM)
C
    DO 80 K=0,IDATA(2)-1
C
C The if loop is to test whether there is any leakage into or out of
C the airway. IDATA(5) > 0 is for air leaks in and IDATA(5) < 0 is for
C air leaks out. Number of the section is also required.
C
      IF (IDATA(5).GT.0.AND.(IDATA(5)-1).EQ.K.AND.ISAVE.EQ.1) THEN
        DO 9 M=0,83
          Q1=VDATA(M)*RDATA(7)
          D1=TTDRY(M,K)
          W1=TTWET(M,K)
          Q2=Q1*(RECFTR(M)/(100.0-RECFTR(M)))
          CALL AIRMIX (Q1,D1,W1,Q2,RECDRY(M),RECWET,
   +              Q3,TTDRY(M,K),TTWET(M,K))
          VDSAVE(M)=VDATA(M)
          VDATA(M)=Q3/RDATA(7)
9       CONTINUE
        ISAVE=0
      ELSEIF ((ABS(IDATA(5))-1).GT.K.AND.NLOOP.EQ.2.
   +        AND.ISAVE.EQ.0) THEN
        ISAVE=1
        DO 12 M=0,83
12        VDATA(M)=VDSAVE(M)
      ENDIF
C
      IF (IDATA(5).LT.0.AND.(ABS(IDATA(5))-1).EQ.K.
   +    AND.ISAVE.EQ.1) THEN
        DO 14 M=0,83
          Q1=VDATA(M)*RDATA(7)
          Q2=Q1*RECFTR(M)/100.0
C
          IF (Q2.EQ.Q1) THEN
            PRINT 13
13            FORMAT(//,' **** Program stop !!! ***',
   +              /,' **** Too much air leakage ****')
            STOP
          ENDIF
C
          Q3=Q1-Q2
          VDSAVE(M)=VDATA(M)
          VDATA(M)=Q3/RDATA(7)
14      CONTINUE
        ISAVE=0
      ELSEIF (IDATA(5).LT.0.AND.(ABS(IDATA(5))-1).GT.K.AND.
   +        NLOOP.EQ.2.AND.ISAVE.EQ.0) THEN
        ISAVE=1
        DO 15 M=0,83
15        VDATA(M)=VDSAVE(M)
      ENDIF
C
      WRITE(6,16)K+1
16    FORMAT
```

```
     +  (/,5X,' Initial temperature prediction at section',I3)
C
      CALL STEMP(SETA,K,IDATA(4),TTDRY,TTWET,DRY1,WET1,ETA)
      ITYPE=1
      CALL  TSOLID(ITYPE,DRY1,WET1,ETA,FI,FIMEAN,NTERM,
     +         T1,RAYVST(K),RDATA(11),RADIUS)
      DO 17 I=0,83
        J=NTERM-83+I
        CALL EVAP(DRY1(J),WET1(J),T1(J),ETA(J),Q,SCONV,SRAD,C,SIGMA)
        AMASS=DENS(P,DRY1(J),WET1(J))*VDATA(I)*RDATA(7)
        QSD=SCONV*(T1(J)-DRY1(J))
        QSW1(I)=(Q-QSD)*2*PI*RADIUS*RDATA(6)/IDATA(2)
        QST1(I)=Q*2*PI*RADIUS*RDATA(6)/IDATA(2)
        QT=(QST1(I)+PMACH(I,K+1)+QCOALT(I,K+1)+QSTLT(I,K+1))/AMASS
        QSWT=(QSW1(I)+QCOALW(I,K+1)+QSTLW(I,K+1))/AMASS
        CALL CALTEM(AMASS,DRY1(J),WET1(J),QT,QSWT,
     +         TTDRY(I,(K+1)),TTWET(I,(K+1)))
17    CONTINUE
C
      IF (IDATA(1).NE.0) THEN
        CALL SAGE(IDATA(4),RDATA(11),CPROCK,RHOROC,RADIUS,
     +         RAYAGE(K+1),FI,FIMEAN,NTERM)
      ENDIF
C
C The number of iterations is recorded
C
      ICOUNT=0
C
18      CALL STEMP(SETA,K+1,IDATA(4),TTDRY,TTWET,DRY2,WET2,ETA)
C
      WRITE(6,19)ICOUNT+1,K+1
19    FORMAT
     +  (10X,' The number of iterations in progress is',I3,
     +       ' at section',I3)
C
        CALL TSOLID(ITYPE,DRY2,WET2,ETA,FI,FIMEAN,NTERM,T2,
     +         RAYVST(K+1),RDATA(11),RADIUS)
        DO 20 J=0,83
          L=NTERM-83+J
          CALL EVAP(DRY2(L),WET2(L),T2(L),ETA(L),Q,SCONV,
     +         SRAD,C,SIGMA)
          AMASS=DENS(P,DRY1(L),WET1(L))*VDATA(J)*RDATA(7)
          QSD=SCONV*(T2(L)-DRY2(L))
          QSW2(J)=(Q-QSD)*2*PI*RADIUS*RDATA(6)/IDATA(2)
          QST2(J)=Q*2*PI*RADIUS*RDATA(6)/IDATA(2)
          AVEQST=(QST1(J)+QST2(J))/2
          AVEQSW=(QSW1(J)+QSW2(J))/2
          QT=(AVEQST+PMACH(J,K+1)+QCOALT(J,K+1)+QSTLT(J,K+1))/AMASS
          QSWT=(AVEQSW+QCOALW(J,K+1)+QSTLW(J,K+1))/AMASS
          VAPOUR(J,K+1)=QSWT/RV(DRY1(L))
          CALL CALTEM(AMASS,DRY1(L),WET1(L),QT,QSWT,
     +         TEMDRY(J),TEMWET(J))
20      CONTINUE
C
        DO 60 J=0,83
          IF(ABS(TEMDRY(J)-TTDRY(J,K+1)).GT.0.10.OR.
     +       ABS(TEMWET(J)-TTWET(J,K+1)).GT.0.10) THEN
            DO 30 L=0,83
              TTDRY(L,K+1)=TEMDRY(L)
              TTWET(L,K+1)=TEMWET(L)
30            CONTINUE
            ICOUNT=ICOUNT+1
            GOTO 18
          ELSEIF(J.EQ.83) THEN
            DO 40 L=0,83
              TTDRY(L,K+1)=TEMDRY(L)
```

```
          TTWET(L,K+1)=TEMWET(L)
40       CONTINUE
        GOTO 80
      ELSEIF(ICOUNT.EQ.30) THEN
        PRINT 50
50       FORMAT(/,' Iteration exceeds 30 times !!!')
      ENDIF
60     CONTINUE
80  CONTINUE
C
C To calculate the heat stored by steelwork(Maneylaws,1985)
C
   IF (STDATA(4).EQ.1.0.AND.NLOOP.EQ.1) THEN
     WRITE (6,82)
82    FORMAT(//,3X,' Calculations of heat flow from steel begins :')
     CALL STEEL(TTDRY,TTWET,SETA,STDATA,IDATA(2),QSTLT,QSTLW)
     WRITE (6,84)
84    FORMAT(/,3X,' End of calculation of heat flow from steel.')
   ENDIF
C
C To calculate the heat from the conveyed coal
C
   IF (IFCOAL.EQ.1.AND.NLOOP.EQ.1) THEN
     WRITE (6,86)
86    FORMAT
   + (//,3X,' Calculations of heat flow from conveyed coal begins :')
     CALL COAL(CDATA,TON,TTDRY,TTWET,NCONV,VDATA,IDATA(2),IDATA(3),
   +          QCOALW,QCOALT)
     WRITE (6,88)
88    FORMAT
   + (/,3X,' End of the calculation of heat flow from conveyed coal')
   ENDIF
C
100 CONTINUE
C
C Output to file
C
   OPEN(2,FILE=FNAME2,STATUS='NEW')
C
   CALL TITLE(2)
C
   WRITE(2,1000)
1000 FORMAT(//,' Transient temperature predictions by Jordan method')
   WRITE(2,1010)
1010 FORMAT(  ' ------------------------------------------------')
C
   WRITE(2,1012)(IDATA(L),L=1,5)
1012 FORMAT(//,5X,' Input Data of Control Integer',
   +      /,5X,' ----------------------------',
   +      //,10X,' Airway type            :',I3,
   +       /,10X,' No. of sections        :',I3,
   +       /,10X,' Type of ventilation    :',I3,
   +       /,10X,' No. of conditioning week :',I3,
   +       /,10X,' Recirculation or leakage :',I3)
C
   WRITE(2,1014)(RDATA(L),L=1,11)
1014 FORMAT(//,5X,' Input Data for Airway',
   +      /,5X,' --------------------',
   +      //,10X,' Average air flow velocity       :',F8.2,' m/s',
   +       /,10X,' Initial virgin strata temperature :',F8.2,' C',
   +       /,10X,' Geothermal gradient             :',F8.2,' C/m',
   +       /,10X,' Initial depth                :',F8.2,' m',
   +       /,10X,' Final depth                  :',F8.2,' m',
   +       /,10X,' Length of airway               :',F8.2,' m',
   +       /,10X,' X sectional area              :',F8.2,' m^2',
   +       /,10X,' Advance rate                  :',F8.2,' m/hr',
```

```
     +     /,10X,' Initial age of the airway        :',E8.2,' hr',
     +     /,10X,' Average wetness factor           :',F8.2,
     +     /,10X,' Thermal conductivity of rock     :',F8.2,' W/m C')
C
      IF (STDATA(4).EQ.1.0) THEN
        STDATA(1)=STDATA(1)*IDATA(2)/RDATA(6)
        STDATA(2)=STDATA(2)*IDATA(2)/RDATA(6)
        WRITE(2,1016)(STDATA(L),L=1,3)
 1016   FORMAT(//,5X,' Input Data of Structural Steel',
     +         /,5X,' ------------------------------',
     +   //,10X,' Surface area of steel           :',F8.2,' m^2/m',
     +    /,10X,' Mass of steel                   :',F8.2,' Kg/m',
     +    /,10X,' Convective heat transfer coeff. :',F8.2,' W/m^2 K')
      ENDIF
C
      IF (IFCOAL.EQ.1) THEN
        WRITE(2,1018) (CDATA(L),L=1,14)
 1018   FORMAT(//,5X,' Input Data of Conveyed Coal',
     +         /,5X,' ---------------------------',
     +   //,10X,' Velocity of conveyed belt       :',F8.2,' m/s',
     +    /,10X,' Width of conveyed belt          :',F8.2,' m',
     +    /,10X,' Length of conveyed belt         :',F8.2,' m',
     +    /,10X,' Number of shifts                :',F8.2,
     +    /,10X,' Roughness of conveyed coal      :',F8.2,' m',
     +    /,10X,' Density of conveyed coal        :',F8.2,' Kg/m^3',
     +    /,10X,' Specific of heat capacity of coal:',F8.2,' J/Kg K',
     +    /,10X,' Themal conductivity of coal     :',F8.2,' W/m K',
     +    /,10X,' Initial wetness factor of coal  :',F8.2,
     +    /,10X,' Final wetness factor of coal    :',F8.2,
     +    /,10X,' Initial temperature of coal     :',F8.2,' C',
     +    /,10X,' Roller radius of conveyed belt  :',F8.2,' mm',
     +    /,10X,' Running time                    :',F8.2,' hr',
     +    /,10X,' % of conveyor power assumed     :',F8.2)
C
        TOLTON=0.0
        DO 1020 L=1,ABS(INT(CDATA(4)))
 1020     TOLTON=TOLTON+TON(L)
        AVETON=TOLTON/(ABS(CDATA(4))*1000)
        WRITE(2,1022)AVETON
 1022   FORMAT(10X,' Average tonnage over all shifts :'
     +         ,E8.2,'ton/hr')
      ENDIF
C
      WRITE(2,1025)
 1025 FORMAT(/)
      WRITE(2,1030)
 1030 FORMAT( ' TIME',3X,' DB1',3X,' WB1',3X,' DB2',3X,' WB2',3X,' EFF2'
     +    ,2X,' QMACH',2X,' QCOALT',2X,' QSTORE',1X,' MOISTURE')
      WRITE(2,1035)
 1035 FORMAT( ' Hour',3X,' C ',3X,' C ',3X,' C ',3X,' C ',3X,'  C '
     +    ,2X,' KW  ',2X,'  KW  ',2X,'  KW  ',1X,' Kg/Kg ',/)
C
      DO 1070 K=0,83
        QCALLD=0.0
        WATER=0.0
        QMALL=0.0
        QSTORE=0.0
        DO 1050 J=1,IDATA(2)
          QCALLD=QCOALT(K,J)/1000+QCALLD
          WATER=VAPOUR(K,J)+WATER
          QMALL=PMACH(K,J)/1000+QMALL
          QSTORE=QSTLT(K,J)/1000+QSTORE
 1050   CONTINUE
        KK=K*2
        WRITE(2,1060)KK,TTDRY(K,0),TTWET(K,0),TTDRY(K,IDATA(2)),
     +       TTWET(K,IDATA(2)),EFFTEM(VDATA(K),TTDRY(K,IDATA(2))
```

```
  +         ,TTWET(K,IDATA(2))),QMALL,QCALLD,QSTORE,WATER
 1060   FORMAT(I4,F9.2,4F7.2,F8.2,2F9.2,F9.3)
 1070 CONTINUE
C
      WRITE(6,1080)
 1080 FORMAT(//,' The program  is FINISH !!')
C
      STOP
      END
C
C ---------------------------------------------------------------
      FUNCTION EFFTEM(VEL,DB,WB)
C  Function to calculate effective temperature. This function is
C  obtained from K.Maughan Thesis (1988).
C
      IF (VEL.LT.3.5) THEN
        C7=5.27+1.3*VEL-1.15*EXP(-2*VEL)
        Z9=(C7-1.35)*(DB-WB)+141.61
        X9=17*((DB-WB)*C7+8.33*(WB-20))/Z9
        Y9=8.33*(17*C7-(C7-1.35)*(WB-20))/Z9
        EFFTEM=(4*(4.12-Y9)+X9)/1.6518+20
        IF (EFFTEM.LT.10.0) THEN
          EFFTEM=101.0
        ENDIF
      ELSE
        EFFTEM=201.0
      ENDIF
      RETURN
      END
C
C----------------------------------------------------------------
      SUBROUTINE TITLE(IOS)
C
      WRITE(IOS,10)
 10   FORMAT(//,15X,' ************************************************',
  +      /,15X,' *                                              *',
  +      /,15X,' *     Department of Mining Engineering         *',
  +      /,15X,' *                                              *',
  +      /,15X,' *     University of Newcastle upon Tyne        *',
  +      /,15X,' *                                              *',
  +      /,15X,' *  Program Name : JCTP.V1                      *',
  +      /,15X,' *                                              *',
  +      /,15X,' *  Developed By Joseph Cheung                  *',
  +      /,15X,' *                                              *',
  +      /,15X,' *  Purpose : Provide transient temperature     *',
  +      /,15X,' *          predictions for roadways.           *',
  +      /,15X,' *                                              *',
  +      /,15X,' *  Heat Sources : Auto compression, strata     *',
  +      /,15X,' *               conveyed coal, machinery and   *',
  +      /,15X,' *               storage by steel.              *',
  +      /,15X,' *                                              *',
  +      /,15X,' ************************************************')
C
      RETURN
      END
C----------------------------------------------------------------
      SUBROUTINE INPUT(PI,RADIUS,SCONV,IFCOAL)
C Subroutine input is to read data only.
C
      CHARACTER*16  FNAME1, FNAME2, OPTION*1
      DIMENSION    IDATA(7), RDATA(12), CDATA(14), VDATA(0:83)
      DIMENSION    SETA(0:83), TTDRY(0:83,0:10), TTWET(0:83,0:10)
      DIMENSION    PRATE(0:83,10),PPART(0:83,10),NCONV(0:83)
      DIMENSION    ADATA(12),PMACH(0:83,10),NPOWER(0:83),STDATA(5)
      DIMENSION    RECFTR(0:83),RECDRY(0:83),RECWET(0:83)
      DIMENSION    TON(10)
```

```
C        .
   COMMON/RINPUT/ IDATA, RDATA, CDATA, TTDRY, TTWET, PMACH,
  +          VDATA,SETA,NCONV,NPOWER,STDATA,FNAME2,
  +          RECFTR,RECDRY,RECWET,TON
C
   PRINT 10
10 FORMAT('&Have you created datafiles? (Y/N)  ')
   READ(5,'(A)') OPTION
C
   IF (OPTION.EQ.'Y'.OR.OPTION.EQ.'y') THEN
     PRINT 20
20    FORMAT('&Please enter the name of input file:')
     READ (5,'(A16)') FNAME1
     PRINT 30
30    FORMAT('&Please enter the name of output file:')
     READ (5,'(A16)')FNAME2
C
     OPEN(1,FILE=FNAME1,STATUS='OLD')
C
     WRITE(6,35)
35    FORMAT(//,' Execution of program begins :')
C
     READ(1,40)(IDATA(I),I=1,5)
40    FORMAT(//5I3)
C
     READ(1,170)
     READ(1,45)(RDATA(I),I=1,11)
C
     READ(1,170)
     READ(1,45)(STDATA(I),I=1,5)
C
     READ(1,170)
     READ(1,45)(CDATA(J),J=1,14)
C
     READ(1,170)
     IF (CDATA(4).LT.0.) THEN
       READ(1,45) TON(1)
       DO 42 J=2,ABS(INT(CDATA(4)))
42         TON(J)=TON(1)
     ELSE
       READ(1,45)(TON(J),J=1,ABS(INT(CDATA(4))))
     ENDIF
C
45    FORMAT(14F10.2)
C
C To initialise the area and mass of the steel per section of roadway
C
     STDATA(1)=STDATA(1)*RDATA(6)/IDATA(2)
     STDATA(2)=STDATA(2)*RDATA(6)/IDATA(2)
C
     READ(1,170)
     DO 60 I=0,83
       IF (IDATA(5).GT.0) THEN
         READ(1,65)TTDRY(I,0),TTWET(I,0),NPOWER(I),NCONV(I),
  +          VDATA(I),SETA(I),RECFTR(I),RECDRY(I),RECWET(I)
       ELSEIF (IDATA(5).LT.0) THEN
         READ(1,65)TTDRY(I,0),TTWET(I,0),NPOWER(I),NCONV(I),
  +          VDATA(I),SETA(I),RECFTR(I)
       ELSE
         READ(1,65)TTDRY(I,0),TTWET(I,0),NPOWER(I),NCONV(I),
  +          VDATA(I),SETA(I)
       ENDIF
60    CONTINUE
C
65      FORMAT(2F10.2,2I5,5F10.2)
C
```

```
      DO 100 I=0,83
        IF (NCONV(I).EQ.1) THEN
C
C To create a factor indicating the conveyor is in operation.
C
          IFCOAL=1
C
C The following equations are obtained from Burrell,1983. The
C heat from the conveyor is calculated
C
          IF (IDATA(1).EQ.2) THEN
            CLEN=CDATA(3)/1000+0.4
          ELSE
            CLEN=CDATA(3)/1000+0.3
          ENDIF
C
          W=0.00058*CDATA(2)*1000*(CDATA(12)-15.6)
          GOTO 110
        ELSE
          IFCOAL=0
        ENDIF
 100    CONTINUE
C
 110    DO 150 I=0,83
        IF (ABS(NPOWER(I)).GT.0) THEN
          CALL RPOWER(NPOWER(I),IDATA(2),NPOWER,PRATE,PPART)
          GOTO 152
        ENDIF
 150    CONTINUE
C
 152    DO 160 I=0,83
        DO 155 J=1,IDATA(2)
C
          IF (NCONV(I).NE.0) THEN
C
C Friction coefficient is assumed to be 0.019
C
            PCH=0.22724*CLEN*(W*CDATA(1)+
   &            (0.278*TON(NCONV(I))*24./(1000*CDATA(13))))
            PCH=PCH*CDATA(14)
          ELSE
            PCH=0.0
          ENDIF
C
          IF (NCONV(I).NE.0.AND.NPOWER(I).NE.0) THEN
            PMACH(I,J)=(PRATE(I,J)*PPART(I,J))+(PCH/IDATA(2))*1000
          ELSEIF(NPOWER(I).NE.0.AND.NCONV(I).EQ.0) THEN
            PMACH(I,J)=PRATE(I,J)*PPART(I,J)*1000
          ELSEIF(NCONV(I).NE.0.AND.NPOWER(I).EQ.0) THEN
            PMACH(I,J)=PCH/IDATA(2)*1000
          ELSE
            PMACH(I,J)=0.0
          ENDIF
 155      CONTINUE
 160    CONTINUE
C
 170    FORMAT(/)
C
C Calculate the equivalent radius of the airway
C
      RADIUS=SQRT(RDATA(7)/PI)
C
C Calculate the heat transfer coefficient. equation via R.Burrel.
C
      SUMVEL=0.0
      DO 185 I=0,83
 185    SUMVEL=VDATA(I)+SUMVEL
```

```
      AVEVEL=SUMVEL/84
      SCONV=5.5*AVEVEL**0.75/((2*RADIUS)**0.25)
    ELSE
      PRINT 180
 180  FORMAT(' Program stop !!'/,
   +         'Please create datafile before using this program.')
    ENDIF
C
 190 RETURN
    END
C------------------------------------------------------------------
    SUBROUTINE RPOWER (NP,MP,NPOWER,PRATE,PPART)
C
C This subroutine is used to read the machine power if the predictions
C are required.
C
    REAL   NPOWER(0:83),PRATE(0:83,10),PPART(0:83,10)
    REAL   DPLACE(10),DRATE(10),DPART(10)
C
C If loop is to determine whether linear power is used.
C
    IF (NP.LT.0) THEN
      READ(1,100)
      READ(1,10)PTOTAL,PERTOL
    ELSE
      READ (1,100)
      READ (1,10) (DPLACE(I),I=1,NP)
      READ (1,100)
      READ (1,10) (DRATE(I),I=1,NP)
      READ (1,100)
      READ (1,10) (DPART(I),I=1,NP)
    ENDIF
 10  FORMAT(10F8.2)
C
    DO 30 J=1,MP
        K=1
C
        DO 20 I=0,83
          IF (NP.GT.0) THEN
            IF (NPOWER(I).GT.0.AND.J.EQ.DPLACE(K)) THEN
              PRATE(I,J)=DRATE(K)
              PPART(I,J)=DPART(K)
            ELSE
              PRATE(I,J)=0.0
              PPART(I,J)=0.0
            ENDIF
          ELSE
            IF (ABS(NPOWER(I)).GT.0.AND.NP.LT.0) THEN
              PRATE(I,J)=PTOTAL/MP
              PPART(I,J)=PERTOL/MP
            ELSE
              PRATE(I,J)=0.0
              PPART(I,J)=0.0
            ENDIF
          ENDIF
 20      CONTINUE
C
        DO 25 I=0,83
          IF (PRATE(I,J).NE.0) THEN
            K=K+1
            GOTO 30
          ENDIF
 25      CONTINUE
 30  CONTINUE
C
 100 FORMAT(/)
    RETURN
```

```
      END
C ---------------------------------------------------------------
      SUBROUTINE INIT(NAWT,N,RDATA,RAYAGE,RAYVST)
C Subroutine INIT is to initialise array for age and vst at different
C sections of the roadway)
C
      DIMENSION  RDATA(12),RAYAGE(0:10),RAYVST(0:10)
C
C Initialise the age  at each section of the airway.
C NAWT=1 is for age increase along the airway, ie. tailgate
C NAWT=2 is for age decrease along the airway, ie, maingate
C constant age is for roadway only.
C
      DO 10 I=0,N
        IF (NAWT.EQ.1) THEN
          RAYAGE(I)=RDATA(9)+RDATA(6)/(N*RDATA(8))*I
        ELSEIF (NAWT.EQ.2) THEN
          RAYAGE(I)=RDATA(9)-RDATA(6)/(N*RDATA(8))*I
        ELSE
          RAYAGE(I)=RDATA(9)
        ENDIF
 10   CONTINUE
C
C Initialise the vst at different section
C
      DO 40 I=0,N
 40     RAYVST(I)=RDATA(2)+(RDATA(5)-RDATA(4))/N*I*RDATA(3)
C
      RETURN
      END
C---------------------------------------------------------------
      SUBROUTINE SAGE(NCON,TROCK,CPROCK,RHOROC,RADIUS,AGE,FI,
     +           FIMEAN,NTERM)
C
C Subroutine to calculate the non-dimensional time
C
      DIMENSION TIME(0:460),FI(0:460),FIMEAN(0:460)
      REAL    AGE
      INTEGER  NCON,NTERM
C
      DO 10 I=0,40
 10     TIME(I)=AGE/40*I*3600
      M=NCON*84+40
      IF (NCON.NE.0) THEN
        DO 20 I=41,M
 20       TIME(I)=TIME(I-1)+2*3600
      ENDIF
      NTERM=M+84
      DO 30 I=M+1,NTERM
 30     TIME(I)=TIME(I-1)+2*3600
C
      DO 40 I=0,NTERM
 40     TIME(I)=TROCK/(RHOROC*CPROCK)*(TIME(I)/(RADIUS**2))
C
      CALL SDELTA(TIME,FI,FIMEAN,NTERM)
      RETURN
      END
C---------------------------------------------------------------
      SUBROUTINE STEEL(TTDRY,TTWET,SETA,STDATA,NSECT,QSTLT,QSTLW)
C
C Subroutine steel is to determine the heat stored by the steel.
C
      DIMENSION TTDRY(0:83,0:10),TTWET(0:83,0:10),SETA(0:83)
      DIMENSION STDATA(5),QSTLT(0:83,10),QSTLW(0:83,10)
C
      COMMON/STLCON/STLCP,STLRAD
C
```

```
      DO 20 I=1,NSECT
        DO 10 J=0,83
          AVETD=(TTDRY(J,I)+TTDRY(J,(I-1)))/2
          AVETW=(TTWET(J,I)+TTWET(J,(I-1)))/2
          IF (J.EQ.0) THEN
            TFIN=AVETD
            QSTLT(J,I)=0.0
            QSTLW(J,I)=0.0
          ELSE
            CALL EVAP(AVETD,AVETW,TFIN,SETA(J),QFLUX,STDATA(3),
     +           STLRAD,HSCONV,THETA)
            STLK=HSCONV*STDATA(1)/(STDATA(2)*STLCP)
            QSTLT(J,I)=(((STDATA(2)*STLCP)/(2*3600))*(TFIN-THETA)*
     +           (1-EXP(-STLK*2*3600)))*STDATA(5)
            QSTLW(J,I)=(((HSCONV-STDATA(3))/HSCONV)*QSTLT(J,I)
     +           +(STDATA(3)*STDATA(1)*(AVETD-THETA)))*STDATA(5)
            TFIN=THETA-((TFIN-THETA)*EXP(-STLK*2*3600))
          ENDIF
 10     CONTINUE
 20   CONTINUE
C
      RETURN
      END
C-------------------------------------------------------------------
      SUBROUTINE COAL(CDATA,TON,TTDRY,TTWET,NCONV,
     +          VDATA,NSECT,IVENT,AVEQCW,AVEQCT)
C
C Subroutine coal is to calculate the surface temperature of the
C conveyed coal and heat from conveyor
C
      DIMENSION CDATA(14),TTDRY(0:83,0:10),TTWET(0:83,0:10)
      DIMENSION VDATA(0:83),CF(0:100),CFMEAN(100),BDRY(0:100)
      DIMENSION BWET(0:100),NCONV(0:83),CFLUX(0:100),TCOAL(0:100)
      DIMENSION AVEQCT(0:83,10),BBWET(0:100),BBDRY(0:100)
      DIMENSION QCWET(0:10),QCT(0:10), AVEQCW(0:83,10)
      DIMENSION CETA(0:100),CONETA(0:460),TON(10)
C
      COMMON/STRATA/SRAD,SCONV,CPROCK,RHOROC,GRA,PI
      COMMON/AIRCON/P,RD,CPAIR
      COMMON/COLCON/CFREE,CRAD,CCONV
C
      DO 50 I=0,83
        IF (NCONV(I).NE.0) THEN
C
C Calculate the thickness of the conveyed coal (Hermanns,1976)
C
          BTHICK=TON(NCONV(I))/(CDATA(6)*CDATA(1)*CDATA(2)*3600)
C
          IF (BTHICK.EQ.0.) THEN
            DO 2 J=1,NSECT
              AVEQCW(I,J)=0.0
              AVEQCT(I,J)=0.0
 2          CONTINUE
            GOTO 50
          ENDIF
C
C Calculate the relative velocity of the ventilation air and
C conveyed coal.
C
        IF (IVENT.EQ.1) THEN
          RELVEL=VDATA(I)+CDATA(1)
        ELSE
          IF (VDATA(I).GT.CDATA(1)) THEN
            RELVEL=VDATA(I)-CDATA(1)
          ELSE
            RELVEL=CDATA(1)-VDATA(I)
```

```
        ENDIF
      ENDIF
C
C Calculate the heat transfer coefficient (W/m^2) (Hermann,1976)
C
      CFORCE=4.5675*(RELVEL**0.79)*(1.0+36*(CDATA(5)**0.79))
C
C Free convective heat transfer = 6.973 W/m^2 (Hermann,1976)
C
      CCONV=SQRT(CFORCE**2+6.973**2)
C
C Calculate the time element
C
      CALL CDELTA (NSECT,CDATA(3),RELVEL,BTHICK,CDATA(6),
     +          CDATA(8),CDATA(7),CF,CFMEAN)
C
C To initialise the wetness factor along the conveyed coal
C
      DO 5 J=0,10*NSECT
 5      CETA(J)=CDATA(9)+((CDATA(10)-CDATA(9))/(10*NSECT)*J)
C
C Initialise the prevailing temperatures over the conveyed coal. The
C temperatures are assumed to vary linearly over the conveyor.
C
      BDRY(0)=TTDRY(I,0)
      BWET(0)=TTWET(I,0)
      DO 20 J=1,NSECT
          DO 10 K=1,10
            L=(J-1)*10+K
            BDRY(L)=TTDRY(I,J-1)+(TTDRY(I,J)-TTDRY(I,J-1))/10*K
            BWET(L)=TTWET(I,J-1)+(TTWET(I,J)-TTWET(I,J-1))/10*K
 10       CONTINUE
 20   CONTINUE
C
C Convert the air temperature if the ventilation is antitropal.
C
        DO 30 J=0,NSECT*10
          IF (IVENT.EQ.1) THEN
            K=NSECT*10-J
            BBDRY(J)=BDRY(K)
            BBWET(J)=BWET(K)
            CONETA(J)=CETA(K)
          ELSE
            BBDRY(J)=BDRY(J)
            BBWET(J)=BWET(J)
            CONETA(J)=CETA(J)
          ENDIF
 30     CONTINUE
C
      ITYPE=0
      CALL TSOLID (ITYPE,BBDRY,BBWET,CONETA,CF,CFMEAN,
     +          (NSECT*10),TCOAL,CDATA(11),CDATA(8),RADIUS)
C
      DO 40 J=0,NSECT
C
        IF (IVENT.EQ.1) THEN
          JJ=10*(NSECT-J)
        ELSE
          JJ=10*J
        ENDIF
C
        CALL EVAP(BBDRY(JJ),BBWET(JJ),TCOAL(JJ),CDATA(9),CFLUX(JJ),
     +          CCONV,CRAD,C,SIGMA)
        QCDRY=CCONV*(TCOAL(JJ)-BBDRY(JJ))
        QCWET(J)=CFLUX(JJ)-QCDRY
        QCT(J)=CFLUX(JJ)
 40   CONTINUE
```

```
C
      DO 45 J=1,NSECT
        AVEQCW(I,J)=(QCWET(J)+QCWET(J-1))/2
   +            *(CDATA(3)*CDATA(2)/NSECT)
        AVEQCT(I,J)=(QCT(J)+QCT(J-1))/2*(CDATA(3)*CDATA(2)/NSECT)
 45     CONTINUE
C
      ELSE
        DO 48 J=1,NSECT
          AVEQCW(I,J)=0.0
          AVEQCT(I,J)=0.0
 48       CONTINUE
      ENDIF

 50  CONTINUE
C
     RETURN
     END
C-----------------------------------------------------------------------
     SUBROUTINE CDELTA( N,BLEN,RELVEL,BTHICK,CRHO,CCOAL,CPCOAL,
    +          CF,CFMEAN)
C
C Subroutine CDELTA is to calculate the temperature functions for conveyed
C coal. The mean of the function is also calculated. The parameter should
C be changed if more accurate temperature function is required.
C
C N      = no of sections in the airway
C BLEN   = length of the belt (m)
C RELVEL = relative velocity of the belt and the ventilation air (m/s)
C BTHICK = thickness of the slab (m)
C CRHO   = density of the conveyed coal (kg/m1/43)
C CPCOAL = specific heat capacity of conveyed coal (J/kgC)
C CF     = tempeature function for the slab
C CFMEAN = the mean of the temperature function for the slab
C
     REAL  CF(0:10*N),CFMEAN(10*N),SUM,ALPHA
C
     COMMON/STRATA/SRAD,SCONV,CPROCK,RHOROC,GRA,PI
C
     ALPHA=CCOAL/(CRHO*CPCOAL)
     NSECT= 10*N
C    WRITE(6,3)ALPHA,NSECT
C3   FORMAT(' ALPHA',F15.5,I10)
C
     DO 10 I=0,NSECT,1
       TIME = BLEN/(RELVEL*NSECT)*I
C      WRITE(6,7)TIME
C7      FORMAT(' TIME =',F15.5)
       DIMENT=ALPHA*TIME/BTHICK**2
C
C Calculate the sum of the transient solution as calculated
C
       SUM=0.0
       DO 5 J=1,50
         X=-(J**2)*PI*PI*DIMENT
C
C This if loop is to provide a zero for the exponential value
C
         IF (X.LT.-70.00) THEN
           X=0.0
         ELSE
           X=EXP(X)/J**2
         ENDIF
         SUM=X+SUM
 5     CONTINUE
C
       CF(I) = BTHICK/(3*CCOAL)+TIME/(BTHICK*CRHO*CPCOAL)
```

```
+       -2*BTHICK/(CCOAL*PI**2)*SUM
 10  CONTINUE
C
     DO 20 I=1,NSECT
       CFMEAN(I) = (CF(I)+CF(I-1))/2
 20  CONTINUE
C    WRITE (6,21) CF(0)
C    WRITE (6,21)(CF(I),CFMEAN(I),I=1,NSECT)
 21  FORMAT(' CF =',2F15.5)
     RETURN
     END
C-----------------------------------------------------------------
     SUBROUTINE SDELTA (S,D,DMEAN,MT)
C
C Subroutine delta calculates the mean of the temperature functions
C I(T) over a period of time t. The functions can be found in
C Jordan's report and Palin's notes. The following functions are obtained
C from the program CJP1 of British Coal, Bretby.
C S    =  the Time array(TIME) used in the main program.
C D    =  the output array of the mean of I(T),(FI).
C DMEAN =  THE MEAN OF I(T),(FIMEAN).
C
     REAL   S(0:MT),D(0:MT),DMEAN(MT)
C
     A(T)= SQRT(T)*T*(1.8561+T*(0.2784+T*0.1044))-T*T*(0.6169+T*
    $   (0.1542+0.08735*T))
     F(T)= SQRT(T)*(2.7842+T*(0.6961+0.3654*T))-T*(1.2337+T*(0.4626+
    $   0.3494*T))
     TU(T)=0.999739109+T*(0.596612146+T*(0.149180912+T*(0.219431676-
    $    T*(0.07505761-0.092950768*T))))
     G(T) =1.00054687-T*(0.01174721-T*(0.078447916-T*(0.1158227-T*(
    $    0.290463655-T*(0.20775397-0.065471369*T)))))
     B(T) =PI*PI*(ALOG(4*T)-0.57722)/8
C
     PI =3.1415926
C
C The do-loop is to calculate the function I(T) as in Jordan's work
     DO  5  I=0,MT
       IF(S(I).LT.1.4) THEN
         D(I)=F(S(I))*G(S(I))
       ELSE
         D(I)=B(S(I))*TU(1/S(I))
       ENDIF
 5   CONTINUE
C
C This do loop is to calculate the mean of the I(T)
C
     DO 10  J=1,MT
 10       DMEAN(J)=(D(J)+D(J-1))/2
C
     RETURN
     END
C-----------------------------------------------------------------
     SUBROUTINE STEMP(SETA,NSECT,NCON,TTDRY,TTWET,DRY1,WET1,ETA)
C
C Subroutine to initialise the air temperatures at the right interval.
C
     DIMENSION  TTDRY(0:83,0:10),TTWET(0:83,0:10),SETA(0:83)
     DIMENSION  DRY1(0:460),WET1(0:460),ETA(0:460)
     REAL     AVEDRY,AVEWET,DRY,WET
     INTEGER   NSECT,NCON
C
       DRY=0.0
       WET=0.0
       SUMETA=0.0
       DO 10 I=0,83
         DRY=TTDRY(I,NSECT)+DRY
```

```
      WET=TTWET(I,NSECT)+WET
      SUMETA=SETA(I)+SUMETA
 10   CONTINUE
     AVEDRY=DRY/84
     AVEWET=WET/84
     AVEETA=SUMETA/84
C
   DO 20 I=0,40
     DRY1(I)=AVEDRY
     WET1(I)=AVEWET
     ETA(I)=AVEETA
 20 CONTINUE
C
   M=40+NCON*84
C
C Initialise the air temperature in the conditioning week
C
   IF (NCON.NE.0) THEN
     DO 30 I=1,NCON
       K=84*(I-1)+1
       L=84*I
       DO 30 J=K,L
         DRY1(40+J)=TTDRY((J-1),NSECT)
         WET1(40+J)=TTWET((J-1),NSECT)
         ETA(40+J)=SETA(J-1)
 30   CONTINUE
   ENDIF
C
C Initialise the air temperature in the production week
C
   DO 40 I=M+1,M+84
     DRY1(I)=TTDRY(I-(M+1),NSECT)
     WET1(I)=TTWET(I-(M+1),NSECT)
     ETA(I)=SETA(I-(M+1))
 40 CONTINUE
C
   RETURN
   END
C-------------------------------------------------------------------
   SUBROUTINE TSOLID(ITYPE,BBDRY,BBWET,ETA,CF,CFMEAN,N,TCOAL,TZERO,
  +            TROCK,RADIUS)
C
C Subroutine TSOLID calculates the surface temperatures of the
C conveyed coal.
C
   DIMENSION BBDRY(0:N),BBWET(0:N),CF(0:N),CFMEAN(N)
   DIMENSION TCOAL(0:N),COAL(3),COALT(3),NSIGN(3)
   DIMENSION FLUX(0:460),DFLUX(460),ETA(0:460)
C
   REAL K
C
   COMMON/STRATA/SRAD,SCONV,CPROCK,RHOROC,GRA,PI
   COMMON/AIRCON/P,RD,CPAIR
   COMMON/COLCON/CFREE,CRAD,CCONV
C
   IF (ITYPE.EQ.1) THEN
     K=4*RADIUS/(PI*PI*TROCK)
     CONV=SCONV
     RAD=SRAD
   ELSE
     K=1.0
     CONV=CCONV
     RAD=CRAD
   ENDIF
C
   DO 50 I=0,N
C
```

```
      IF (I.NE.0) THEN
C
C Initialise two guesses for the surface temperature of strata
C
        IF (BBDRY(I).GT.TCOAL(0)) THEN
          COAL(1)=BBDRY(I)
        ELSE
          COAL(1)=TCOAL(0)
        ENDIF
        COAL(2)=BBWET(I)
        IFLAG=0
 10       DO 30 II=1,2
C
          CALL EVAP(BBDRY(I),BBWET(I),COAL(II),ETA(I),FLUX(I),
     +          CONV,RAD,C,SIGMA)
C
C Calculate the difference in flux
C
          DFLUX(I)=FLUX(I)-FLUX(I-1)
C
C Summation of the convolution series
C
          TAREA=0.0
          DO 20 J=1,I
            JJ=I-J+1
            AREA=CFMEAN(JJ)*DFLUX(J)
            TAREA=AREA+TAREA
 20         CONTINUE
C
C Calculate the surface temperature (Jordan, 1965)
C
          COALT(II)=TCOAL(0)-(K*(FLUX(0)*CF(I)+TAREA))
C
          IF (COALT(II).GT.COAL(II)) THEN
            NSIGN(II)=1
          ELSE
            NSIGN(II)=0
          ENDIF
C
C To ensure the guesses have different signs
C
          IF (II.EQ.2) THEN
            IF (NSIGN(1).EQ.NSIGN(2)) THEN
              COAL(1)=COAL(1)+1
              COAL(2)=COAL(2)-1
              GOTO 10
            ENDIF
          ENDIF
C
 30       CONTINUE
C
C Initialise the 3rd guess
C
        ICOUNT=1
C
 35       COAL(3)=(COAL(1)+COAL(2))/2
        CALL EVAP(BBDRY(I),BBWET(I),COAL(3),ETA(I),FLUX(I),
     +          CONV,RAD,C,SIGMA)
C
C Calculate the difference in flux
C
        DFLUX(I)=FLUX(I)-FLUX(I-1)
C
C Summation of the convolution series
C
        TAREA=0.0
        DO 40 J=1,I
```

```
          JJ=I-J+1
          AREA=CFMEAN(JJ)*DFLUX(J)
          TAREA=AREA+TAREA
 40      CONTINUE
C
C Calculate the surface temperature (Jordan, 1965)
C
        COALT(3)=TCOAL(0)-(K*(FLUX(0)*CF(I)+TAREA))
C
C The variable ICOUNT is to count the iterations
C
        ICOUNT=ICOUNT+1
        IF (ICOUNT.GT.20) THEN
          PRINT 45
 45       FORMAT(/,' Iteration exceeds 20 times !')
        ENDIF
C
C To check if the coal(3) agrees with F(coal(3))
C
        IF (ABS(COALT(3)-COAL(3)).GT.0.05) THEN
          IF (COALT(3).GT.COAL(3)) THEN
            NSIGN(3)=1
          ELSE
            NSIGN(3)=0
          ENDIF
          IF (NSIGN(3).EQ.NSIGN(1)) THEN
            COAL(1)=COAL(3)
            COALT(1)=COALT(3)
          ELSE
            COAL(2)=COAL(3)
            COALT(2)=COALT(3)
          ENDIF
          GOTO 35
        ELSE
          TCOAL(I)=COALT(3)
          CALL EVAP(BBDRY(I),BBWET(I),TCOAL(I),ETA(I),FLUX(I),
   +           CONV,RAD,C,SIGMA)
        ENDIF
C
      ELSE
        TCOAL(0)=TZERO
        CALL EVAP(BBDRY(0),BBWET(0),TCOAL(0),ETA(0),FLUX(I),CONV,
   +         RAD,C,SIGMA)
      ENDIF
C
 50  CONTINUE
C
    RETURN
    END
C
C-----------------------------------------------------------------------
    SUBROUTINE  EVAP(DB,WB,TSURF,ETA,QFLUX,CONV,RAD,C,SIGMA)
C
C Subroutine EVAP is to calculate the heat flux for a partially wetted
C surface. This includes the strata surface and the conveyed coal.
C
C DB     = dry bulb temperature (C)
C WB     = wet bulb temperature (C)
C T      = surface temperature (C)
C ETA    = wetness factor
C Qflux  = total heat flux (W/m1/42)
C CONV   = convective heat transfer coefficient (W/M1/42)
C RAD    = radiative heat tansfer coefficient (W/M1/42)
C P      = absolut air pressure (Pa)
C RD     = gas constant of air (Nm/kgC)
C CPAIR  = specific heat capacity of air
C
```

```
      COMMON/AIRCON/P,RD,CPAIR
C
C Equation for saturation pressure (Pa) at temperature
C
      SVP(T)=613.1*EXP(T*(0.0725526-T*(0.000289154-T*0.000000818529)))
C
C Equation for prevailing vapour pressure (Pa)
C
      PRE(P,D,W)=SVP(W)-0.000666*P*(D-W)
C
C  Following equation from Burrell and Maneylaws, 1985
C
      TDENS=3.48*(P-0.3762*PRE(P,DB,WB))/1000
      RV=2497000-2250*DB
      C11=RV/(RD*CPAIR*TDENS)
      C4=C11*CONV*ETA/(CONV+RAD)
      C1=1+C4*SVP(TSURF)/TSURF
      C =C1*(CONV+RAD)
      SIGMA=(DB+C4*PRE(P,DB,WB))/C1
      QFLUX=C*(TSURF-SIGMA)
C
      RETURN
      END
C-----------------------------------------------------------------
C
      SUBROUTINE  CALTEM(AMASS,DB1,WB1,QT,QWET,DB2,WB2)
C
C Subroutine CALTEM  calculates the change in temperatures due
C to the flow of heat flux into the roadway. The new temperature
C is defined by DB2 and WB2.
C The following functions for the psychrometry are obtained
C from British Coal. Saturation vapour pressure is SVP in Pa;
C prevailing pressure is PRE in Pa; density is DENS in kg/m1/43;
C mixing ratio is MIX in kg/kg; relative humidity is RH in %;
C and enthalpy is ENT in kJ/kg.
C
      COMMON/AIRCON/P,RD,CPAIR
C
      SVP(T)=613.6*EXP(T*(0.0725526-T*(0.000289154-T*0.000000818529)))
      DSVP(T)=613.6*EXP(T*(0.0725526-T*(0.000289154-T*0.000000818529)))
     $      *(0.0725526-T*(2*0.000289154-3*T*0.000000818529))
      PRE(P,D,W)=SVP(W)-0.000666*P*(D-W)
      DENS(P,D,W)=3.48*(P-0.378*PRE(P,D,W))/(1000*(273+D))
      AMIX(P,D,W)=0.622*PRE(P,D,W)/(P-PRE(P,D,W))
      RH(P,D,W)=100*PRE(P,D,W)/SVP(D)
      RV(T)=2497000-2250*T
      ENT(P,D,W)=4.187*D*(0.24+0.45*AMIX(P,D,W))+2500*AMIX(P,D,W)
C
      ADDMIX=QWET/(RV(DB1))
      AMIX2=ADDMIX+AMIX(P,DB1,WB1)
      ENT2=QT/1000+ENT(P,DB1,WB1)
      DB2=(ENT2-2500*AMIX2)/(4.187*(0.24+0.45*AMIX2))
      PAIR2=P*AMIX2/(AMIX2+0.622)
      RH2=(PAIR2/SVP(DB2))*100
C
      CALL WETBUL(DB2,WB2,RH2,PAIR2,ENT2,WB1)
C
      RETURN
      END
C
C-----------------------------------------------------------------
C Subroutine to calculate the wet bulb temperature
C
      SUBROUTINE WETBUL(D,W,RH,PAIR,ENT,GW)
C
      COMMON/AIRCON/P,RD,CPAIR
C
```

```
      SVP(T)=613.6*EXP(T*(0.0725526-T*(0.000289154-T*0.000000818529)))
      DSVP(T)=613.6*EXP(T*(0.0725526-T*(0.000289154-T*0.000000818529)))
     $      *(0.0725526-T*(2*0.000289154-3*T*0.000000818529))
      PRE(P,D,W)=SVP(W)-0.000666*P*(D-W)
C
      IF (RH.GT.100.0) THEN
        DO 10 I=1,30
          D=D+3.6/4*(PAIR-(0.98*SVP(D)))/1000
          AMIX=(ENT-4.187*0.24*D)/(4.187*0.45*D+2500)
          PAIR=P*AMIX/(AMIX+0.622)
          RH=(PAIR/SVP(D))*100
C
          IF (RH.LT.100.0) THEN
            GOTO 20
          ELSEIF (I.EQ.30) THEN
            PRINT 5
5           FORMAT(' !!!! Iterations are too great ???')
          ENDIF
10      CONTINUE
      ENDIF
C
20    WB=GW
      C=PAIR+6.66E-4*P*D
      DO 30 I=1,10
        W =WB-((SVP(WB)+6.66E-4*P*WB-C)/(DSVP(WB)+6.66E-4*P))
        IF (ABS(W-WB).LT.0.010) THEN
          GOTO 40
        ELSEIF (I.EQ.10) THEN
          PRINT 25
25        FORMAT(' !! Iterations are too great !!')
        ELSE
          WB=W
        ENDIF
30    CONTINUE
C
40    RETURN
      END
C-----------------------------------------------------------------
      SUBROUTINE AIRMIX(Q1,D1,W1,Q2,D2,W2,Q3,D3,W3)
C
      COMMON/AIRCON/P,RD,CPAIR
C
      SVP(T)=613.6*EXP(T*(0.0725526-T*(0.000289154-T*0.000000818529)))
      DSVP(T)=613.6*EXP(T*(0.0725526-T*(0.000289154-T*0.000000818529)))
     $      *(0.0725526-T*(2*0.000289154-3*T*0.000000818529))
      PRE(P,D,W)=SVP(W)-0.000666*P*(D-W)
      DENS(P,D,W)=3.48*(P-0.378*PRE(P,D,W))/(1000*(273+D))
      AMIX(P,D,W)=0.622*PRE(P,D,W)/(P-PRE(P,D,W))
      RH(P,D,W)=100*PRE(P,D,W)/SVP(D)
      RV(T)=2497000-2250*T
      ENT(P,D,W)=4.187*D*(0.24+0.45*AMIX(P,D,W))+2500*AMIX(P,D,W)
C
C Calculate the mass flow rate and moisture contents
C
      AM1=Q1*DENS(P,D1,W1)
      AM2=Q2*DENS(P,D2,W2)
      V1=AMIX(P,D1,W1)
      V2=AMIX(P,D2,W2)
C
C Calculate the specific enthalpy and moisture content
C
      SPEENT=(ENT(P,D1,W1)*AM1+ENT(P,D2,W2)*AM2)/(AM1+AM2)
      SPECV=(V1*AM1+V2*AM2)/(AM1+AM2)
C
C Calculate the dry bulb temperature
C
      Q3=Q1+Q2
```

```
      D3=(SPEENT-2500*SPECV)/(4.187*(0.24+0.45*SPECV))
      PAIR3=P*SPECV/(SPECV+0.622)
      RH3=(PAIR2/SVP(DB3))*100
C
      CALL WETBUL(D3,W3,RH3,PAIR3,SPEENT,MIN(W1,W2))
      RETURN
      END
C-----------------------------------------------------------------
      BLOCKDATA
C
      COMMON/STRATA/SRAD,SCONV,CPROCK,RHOROC,GRA,PI
      COMMON/AIRCON/P,RD,CPAIR
      COMMON/COLCON/CFREE,CRAD,CCONV
      COMMON/STLCON/STLCP,STLRAD
C
C CPROCK = specific heat capacity for rock (Cornwell, 1981, p237)
C RHOAIR = density of rock (Cornwell, 1981)
C GRA    = acceleration due to gravity (m/s)
C P      = absolute pressure of air (Pa)
C RD     = gas constant of air (Nm/kg C)
C CPAIR  = specific heat capacity of air (Cornwell, 1980)
C CFREE  = convective heat tranfer coefficient of conveyed coal (W/m1/42)
C          (Herman, 1976)
C CRAD   = radiative heat transfer coefficient of conveyed coal (W/m1/42)
C          (Herman, 1976)
C
      DATA   SRAD,CPROCK,RHOROC,GRA,PI
     +       /1.1,887.0,2500.0,9.81,3.1415926/
      DATA   P,RD,CPAIR/1.0E5,465.0,1005.0/
      DATA   CFREE,CRAD/6.793,6.793/
      DATA   STLCP,STLRAD/465.0,1.2/
C
      END
```

APPENDIX II

INPUT DATA FILE

A typical input data file for the transient programme is shown in next section. The contents of this data file is discussed as follows:

Line 1 : This line is for comments and it can be left blank.

Line 2 : This line for comments.

Line 3 : IDATA(5) [Format (5I3)]

IDATA(1)	=	type of roadway
	=	0 when the roadway has a constant age
	=	1 when the roadway is a tailgate, of which the age increases along the length of the roadway
	=	2 when the roadway is a maingate, of which the age decreases along the length of the roadway
IDATA(2)	=	number of sections in the roadway
IDATA(3)	=	type of ventilation
	=	0 when homotropal ventilation is taking place
	=	1 when antitropal ventilation is taking place
IDATA(4)	=	number of conditioning week, only one conditioning week is allowed in this programme
IDATA(5)	=	leakage at the start of the roadway
	=	0 when no ventilation is mixed at the first junction
	=	1 when ventilation is mixed at the first junction

Line 4 : This line is for comments.

Line 5 : This line is for comments.

Line 6 : RDATA(11) [Format(14F10.2)]

RDATA(1)	=	average air flow velocity (m/s)
RDATA(2)	=	initial virgin strata temperature (°C)
RDATA(3)	=	geothermal gradient (°C/m)

RDATA(4) = initial depth (m)

RDATA(5) = final depth (m)

RDATA(6) = length of the roadway (m)

RDATA(7) = X-sectional area (m^2)

RDATA(8) = advance rate (m/hr)

RDATA(9) = initial age of the roadway (hr)

RDATA(10) = average wetness factor

RDATA(11) = thermal conductivity of rock

Line 7 : This line is for comments.

Line 8 : This line is for comments.

Line 9 : STDATA(5) [Format(14F10.2)]

STDATA(1) = surface area of the steel (m^2)

STDATA(2) = mass of the steel (kg/m)

STDATA(3) = convective heat transfer for the steel (W/m^2)

STDATA(4) = control number

= 0 when the steel subroutine is inactive

= 1 when the steel subroutine is active

STDATA(5) = proportions of the heat from the steel

Line 10 : This line is for comments.

Line 11 : This line is for comments.

Line 12 : CDATA(13) [Format(14F10.2)]

CDATA(1) = velocity of the conveyed belt (m/s)

CDATA(2) = width of the conveyed belt (m)

CDATA(3) = length of the conveyed belt (m)

CDATA(4) = number of shifts

> 0 when the tonnage is constant over the four shifts

< 0 when the tonnage is different in each shift

CDATA(5) = roughness of the conveyed coal (m)

CDATA(6) = density of the conveyed coal (kg/m^3)

CDATA(7) = specific heat capacity of the conveyed coal (J/kg K)

CDATA(8) = thermal conductivity of the conveyed coal (W/m K)

CDATA(9) = initial wetness factor of the conveyed coal

CDATA(10) = final wetness factor

CDATA(11) = initial temperature of coal (°C)

CDATA(12) = roller radius of the conveyor belt (mm)

CDATA(13) = running time (hr/day)

Line 13 : This is for comments

Line 14 : This is for comments

Line 15 : TON(I)

TON(1) = tonnage in the first shift (ton/hr)

TON(2) = tonnage in the second shift (ton/hr)

TON(3) = tonnage in the third shift (ton/hr)

TON(4) = tonnage in the fourth shift (ton/hr)

Line 16 : This line is for comments

Line 17 : This line is for comments

Line 18 - 101 : If IDATA(5) > 0, enter the following:
TTDRY(I,0), TTWET(I,0), NPOWER(I), NCONV(I), VDATA(I), SETA(I), RECFTR(I), RECDRY(I), RECWET(I) [Format(2F10.2, 2I5, 5F10.2)]

TTDRY(I,0) = dry bulb temperature of the air at the start of the roadway (°C)

TTWET(I,0) = wet bulb temperature of the air at the start of the roadway (°C)

NPOWER(I) = control integer for machinery indicating number of the machinery sources in the roadway

NCONV(I) = control integer for conveyor

= 0 when the conveyor is inactive

> 0 when the conveyor is active and the integer entered indicates the number of a shift

VDATA(I) = air velocity (m/s)

SETA(I) = wetness factor

RECFTR(I) = control integer

= 0 when there is leakage at the start of the roadway

= 1 when the leakage occurs at the start of the roadway

RECDRY(I) = dry bulb temperature of the leakage air (°C)

RECWET(I) = wet bulb temperature of the leakage air (°C)

If IDATA(5) < 0, only the first six data are required.

Line 102 : This line is for comments

Line 103 : This line is for comments

Line 104 : DPLACE(I) [Format (10F8.2)]

DPLACE(I) = position of the machinery in the roadway

Line 105 : DRATE(I) [Format (10F8.2)]

DRATE(I) = the power rating of the machinery

Line 106 : DPART(I) [Format(10F8.2)]

DPART(I) = proportions of the machinery heat appearing as heat

A2.1 A TYPICAL INPUT DATA FILE

```
The data is to test the program CLIMATE.FOR
Integer control data IDATA(7): Awt, Nsect, Ivent, Iweek, Nleak
0,5,1,1,0,
Road data: RDATA(11)
VFLOW, VST, GEO, IDEP, ODEP, LTH, XSA, ADV, AGE, ETAO, TROCK
2.306,38.3,0.033,913.0,913.0,480.0,12.4,0.38,4032.0,0.05,2.69,
Data for heat storage by steel: STDATA(4)
AREA(m^2/m),MASS(kg/m),STCONV,CONTROL NUMBER, % OF HEAT STORED
17.0,610.0,6.5,0.0,0.5,
CDATA: input data for the heat from conveyor CDATA(13)
relvel,width,length,Ton,Rough,Densy,Cpcoal,Tcoal,Eta,Itcoal,Rdia,Rtime,%POWER
2.35,1.070,500.,-4.,0.02,1350.,1130.,0.5,0.3,0.3,27.50,127.,15.,1.0,
RUN OF MINES : Tonage
TON(I) to TON(CDATA(4))
309866.0,378500.,248500.,0.,
Temperature, Power code and Conveyor code:
Dry bulb, Wet bulb, Npower, Nconv, Vdata(I), Seta(I), RECFTR(I), DB(I), WB(I)
   21.24   18.43  0  1   2.306   0.050
   21.46   18.32  0  0   2.306   0.050
   21.58   18.65  0  1   2.306   0.050
   21.68   17.90  0  2   2.306   0.050
   21.46   17.30  0  2   2.306   0.050
   21.44   16.87  0  2   2.306   0.050
   21.25   16.44  0  0   2.306   0.050
```

21.14	16.49	0	0	2.306	0.050
21.38	17.49	0	0	2.306	0.050
21.31	16.72	0	0	2.306	0.050
22.00	17.53	0	3	2.306	0.050
22.12	17.55	0	3	2.306	0.050
22.87	18.88	0	1	2.306	0.050
22.42	19.07	0	1	2.306	0.050
22.28	18.99	0	1	2.306	0.050
21.82	18.44	0	2	2.306	0.050
21.69	17.50	0	2	2.306	0.050
21.53	16.87	0	2	2.306	0.050
22.41	17.16	0	4	2.306	0.050
22.46	18.13	0	0	2.306	0.050
22.40	17.26	0	4	2.306	0.050
21.43	16.44	0	3	2.306	0.050
21.53	15.55	0	3	2.306	0.050
21.16	14.78	0	3	2.306	0.050
21.16	15.82	0	1	2.306	0.050
21.66	16.27	0	1	2.306	0.050
21.00	15.73	0	1	2.306	0.050
21.01	15.91	0	2	2.306	0.050
20.78	15.54	0	2	2.306	0.050
20.41	14.81	0	2	2.306	0.050
19.95	13.51	0	4	2.306	0.050
19.67	12.88	0	0	2.306	0.050
19.60	13.40	0	0	2.306	0.050
19.80	13.76	0	0	2.306	0.050
19.99	13.87	0	0	2.306	0.050
20.35	13.69	0	0	2.306	0.050
19.85	13.08	0	0	2.306	0.050
20.12	13.21	0	0	2.306	0.050
20.47	13.95	0	0	2.306	0.050
19.98	13.67	0	0	2.306	0.050
19.74	13.41	0	0	2.306	0.050
19.81	13.42	0	0	2.306	0.050
19.99	13.57	0	0	2.306	0.050
19.91	13.53	0	0	2.306	0.050
19.79	13.39	0	0	2.306	0.050
20.17	13.50	0	0	2.306	0.050
19.97	13.16	0	0	2.306	0.050
19.68	12.78	0	0	2.306	0.050
19.83	12.74	0	0	2.306	0.050
20.25	12.86	0	0	2.306	0.050
20.76	13.50	0	0	2.306	0.050
20.12	13.13	0	0	2.306	0.050
19.98	13.05	0	0	2.306	0.050
19.89	13.12	0	0	2.306	0.050
19.93	13.28	0	0	2.306	0.050
20.29	13.60	0	0	2.306	0.050
20.20	13.53	0	0	2.306	0.050
20.17	13.52	0	4	2.306	0.050
20.41	13.59	0	4	2.306	0.050
20.60	13.95	0	4	2.306	0.050
20.93	15.48	0	1	2.306	0.050
20.72	15.89	0	1	2.306	0.050
20.70	15.80	0	1	2.306	0.050
20.86	15.90	0	2	2.306	0.050
20.40	15.54	0	2	2.306	0.050
20.22	14.63	0	2	2.306	0.050
20.31	13.77	0	4	2.306	0.050
20.20	13.56	0	4	2.306	0.050
20.48	14.86	0	4	2.306	0.050
19.99	14.30	0	3	2.306	0.050
20.50	13.97	0	3	2.306	0.050
19.78	13.21	0	3	2.306	0.050
20.07	14.14	0	1	2.306	0.050
20.68	15.48	0	1	2.306	0.050

20.18	15.32	0	1	2.306	0.050
20.24	15.51	0	2	2.306	0.050
19.40	14.73	0	2	2.306	0.050
19.35	14.00	0	2	2.306	0.050
19.51	13.55	0	4	2.306	0.050
19.73	13.64	0	4	2.306	0.050
19.47	14.30	0	4	2.306	0.050
19.51	14.66	0	3	2.306	0.050
20.43	15.32	0	3	2.306	0.050
20.50	14.92	0	3	2.306	0.050

APPENDIX III

OUTPUT DATA FILES

The following output files are obtained from the temperature predictions made for all the sites at Wearmouth and Whitemoor Collieries.

A3.1 WEARMOUTH COLLIERY

A3.1.1 Main Drift

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	0
No. of sections	:	5
Type of ventilation	:	1
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	2.94	m/s
Initial virgin strata temperature	:	26.00	C
Geothermal gradient	:	0.04	C/m
Initial depth	:	1850.00	m
Final depth	:	1850.00	m
Length of airway	:	500.00	m
X sectional area	:	11.30	m^2
Advance rate	:	0.08	m/hr
Initial age of the airway	:	0.26E+05	hr
Average wetness factor	:	0.01	
Thermal conductivity of rock	:	2.69	W/m C

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg
						0.0	0.0	0.0	
0	25.76	21.77	25.58	21.71	16.33	0.0	0.0	0.0	-0.000
2	25.88	21.94	25.67	21.87	16.47	0.0	0.0	0.0	-0.000
4	25.99	22.05	25.79	21.98	16.64	0.0	0.0	0.0	-0.000
6	25.98	22.12	25.80	22.06	16.68	0.0	0.0	0.0	-0.000
8	25.98	22.16	25.80	22.10	16.68	0.0	0.0	0.0	-0.000
10	25.97	22.16	25.80	22.11	16.69	0.0	0.0	0.0	-0.000
12	25.97	22.16	25.80	22.10	16.68	0.0	0.0	0.0	-0.000
14	25.96	22.17	25.80	22.12	16.69	0.0	0.0	0.0	-0.000

16	25.96	22.17	25.81	22.12	16.70	0.0	0.0	0.0	-0.000
18	25.95	22.17	25.80	22.12	16.69	0.0	0.0	0.0	-0.000
20	25.95	22.17	25.78	22.12	16.67	0.0	0.0	0.0	-0.000
22	25.94	22.17	25.78	22.12	16.66	0.0	0.0	0.0	-0.000
24	25.94	22.17	25.78	22.12	16.67	0.0	0.0	0.0	-0.000
26	25.93	22.17	25.78	22.12	16.67	0.0	0.0	0.0	-0.000
28	25.93	22.17	25.77	22.12	16.66	0.0	0.0	0.0	-0.000
30	25.92	22.18	25.76	22.13	16.64	0.0	0.0	0.0	-0.000
32	25.92	22.18	25.74	22.12	16.63	0.0	0.0	0.0	-0.000
34	25.91	22.18	25.74	22.13	16.63	0.0	0.0	0.0	-0.000
36	25.91	22.18	25.75	22.13	16.63	0.0	0.0	0.0	-0.000
38	25.90	22.18	25.74	22.13	16.62	0.0	0.0	0.0	-0.000
40	25.90	22.18	25.74	22.13	16.62	0.0	0.0	0.0	-0.000
42	25.89	22.18	25.73	22.13	16.61	0.0	0.0	0.0	-0.000
44	25.89	22.18	25.72	22.13	16.60	0.0	0.0	0.0	-0.000
46	25.88	22.19	25.71	22.14	16.60	0.0	0.0	0.0	-0.000
48	25.89	22.26	25.72	22.21	16.63	0.0	0.0	0.0	-0.000
50	25.91	22.37	25.75	22.32	16.68	0.0	0.0	0.0	-0.000
52	25.93	22.28	25.77	22.23	16.69	0.0	0.0	0.0	-0.000
54	25.92	22.21	25.78	22.17	16.68	0.0	0.0	0.0	-0.000
56	25.91	22.32	25.77	22.28	16.70	0.0	0.0	0.0	-0.000
58	25.90	22.31	25.75	22.26	16.68	0.0	0.0	0.0	-0.000
60	25.89	22.12	25.75	22.07	16.62	0.0	0.0	0.0	-0.000
62	25.89	22.21	25.77	22.17	16.67	0.0	0.0	0.0	-0.000
64	25.89	22.14	25.78	22.10	16.66	0.0	0.0	0.0	-0.000
66	25.89	22.29	25.78	22.25	16.71	0.0	0.0	0.0	-0.000
68	25.89	22.34	25.79	22.31	16.73	0.0	0.0	0.0	-0.000
70	25.79	22.13	25.73	22.11	16.60	0.0	0.0	0.0	-0.000
72	25.67	22.14	25.61	22.12	16.48	0.0	0.0	0.0	-0.000
74	25.62	22.01	25.56	21.99	16.38	0.0	0.0	0.0	-0.000
76	25.58	22.04	25.54	22.03	16.36	0.0	0.0	0.0	-0.000
78	25.54	22.08	25.49	22.06	16.32	0.0	0.0	0.0	-0.000
80	25.79	22.34	25.65	22.30	16.56	0.0	0.0	0.0	-0.000
82	25.75	22.23	25.69	22.21	16.58	0.0	0.0	0.0	-0.000
84	25.54	21.81	25.49	21.79	16.25	0.0	0.0	0.0	-0.000
86	25.32	21.49	25.32	21.49	15.97	0.0	0.0	0.0	-0.000
88	25.13	21.23	25.15	21.24	15.71	0.0	0.0	0.0	0.000
90	25.04	21.13	25.05	21.13	15.57	0.0	0.0	0.0	0.000
92	24.97	21.04	25.00	21.05	15.49	0.0	0.0	0.0	0.000
94	24.91	20.96	24.93	20.97	15.40	0.0	0.0	0.0	0.000
96	24.86	20.91	24.88	20.92	15.33	0.0	0.0	0.0	0.000
98	24.82	20.85	24.85	20.86	15.28	0.0	0.0	0.0	0.000
100	24.77	20.80	24.82	20.82	15.23	0.0	0.0	0.0	0.000
102	24.74	20.75	24.79	20.77	15.18	0.0	0.0	0.0	0.000
104	24.72	20.71	24.77	20.73	15.15	0.0	0.0	0.0	0.000
106	24.69	20.66	24.74	20.68	15.11	0.0	0.0	0.0	0.000
108	24.65	20.62	24.69	20.63	15.04	0.0	0.0	0.0	0.000
110	24.61	20.58	24.63	20.59	14.96	0.0	0.0	0.0	0.000
112	24.59	20.55	24.61	20.56	14.93	0.0	0.0	0.0	0.000
114	24.58	20.53	24.60	20.54	14.91	0.0	0.0	0.0	0.000
116	24.55	20.52	24.57	20.53	14.88	0.0	0.0	0.0	0.000
118	24.52	20.49	24.54	20.50	14.83	0.0	0.0	0.0	0.000
120	24.49	20.45	24.50	20.45	14.78	0.0	0.0	0.0	0.000
122	24.49	20.42	24.49	20.42	14.76	0.0	0.0	0.0	0.000
124	24.49	20.41	24.49	20.41	14.76	0.0	0.0	0.0	0.000
126	24.50	20.40	24.50	20.40	14.77	0.0	0.0	0.0	0.000
128	24.58	20.48	24.56	20.47	14.85	0.0	0.0	0.0	-0.000
130	24.66	20.57	24.64	20.56	14.97	0.0	0.0	0.0	-0.000
132	24.82	20.83	24.78	20.82	15.18	0.0	0.0	0.0	-0.000
134	24.93	21.32	24.89	21.31	15.42	0.0	0.0	0.0	-0.000
136	25.05	21.57	24.97	21.54	15.57	0.0	0.0	0.0	-0.000
138	25.18	21.63	25.09	21.60	15.72	0.0	0.0	0.0	-0.000
140	25.20	21.77	25.13	21.75	15.81	0.0	0.0	0.0	-0.000
142	25.21	21.75	25.13	21.72	15.80	0.0	0.0	0.0	-0.000
144	25.31	21.78	25.21	21.75	15.90	0.0	0.0	0.0	-0.000
146	25.37	21.99	25.26	21.95	16.01	0.0	0.0	0.0	-0.000

148	25.38	22.02	25.27	21.98	16.03	0.0	0.0	0.0	-0.000
150	25.39	21.91	25.28	21.88	16.02	0.0	0.0	0.0	-0.000
152	25.41	21.96	25.30	21.93	16.06	0.0	0.0	0.0	-0.000
154	25.42	21.85	25.33	21.82	16.06	0.0	0.0	0.0	-0.000
156	25.43	21.96	25.35	21.93	16.11	0.0	0.0	0.0	-0.000
158	25.41	22.03	25.33	22.00	16.11	0.0	0.0	0.0	-0.000
160	25.35	21.89	25.28	21.87	16.02	0.0	0.0	0.0	-0.000
162	25.38	21.98	25.29	21.95	16.05	0.0	0.0	0.0	-0.000
164	25.51	22.12	25.41	22.09	16.22	0.0	0.0	0.0	-0.000
166	25.63	21.90	25.52	21.86	16.30	0.0	0.0		-0.000

A3.1.2 Conveyor roadway

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	0
No. of sections	:	8
Type of ventilation	:	1
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	0.75	m/s
Initial virgin strata temperature	:	26.00	C
Geothermal gradient	:	0.04	C/m
Initial depth	:	1850.00	m
Final depth	:	1850.00	m
Length of airway	:	400.00	m
X sectional area	:	11.10	m^2
Advance rate	:	0.08	m/hr
Initial age of the airway	:	0.18E+05	hr
Average wetness factor	:	0.05	
Thermal conductivity of rock	:	2.69	W/m C

Input Data of Conveyed Coal

Velocity of conveyed belt	:	2.35	m/s
Width of conveyed belt	:	1.07	m
Length of conveyed belt	:	400.00	m
Number of shifts	:	4.00	
Roughness of conveyed coal	:	0.02	m
Density of conveyed coal	:	1350.00	Kg/m^3
Specific of heat capacity of coal	:	1130.00	J/Kg K
Thermal conductivity of coal	:	0.70	W/m K
Initial wetness factor of coal	:	0.25	
Final wetness factor of coal	:	0.25	
Initial temperature of coal	:	25.75	C
Roller radius of conveyed belt	:	127.00	mm
Running time	:	20.00	hr
% of conveyor power assumed	:	1.00	
Average tonnage over all shifts	:	0.13E+03	ton/hr

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg
0	24.96	21.58	26.15	23.15	21.61	34.85	22.73	0.0	0.002
2	24.90	21.46	26.22	23.13	21.64	34.85	25.26	0.0	0.002
4	24.85	21.40	26.23	23.11	21.64	34.85	26.27	0.0	0.002
6	24.80	21.36	26.25	23.11	21.65	34.85	27.28	0.0	0.002
8	24.77	21.27	26.29	23.09	21.66	34.85	29.73	0.0	0.002
10	24.75	21.20	26.19	22.99	21.55	34.85	27.24	0.0	0.002
12	24.73	21.19	25.89	22.86	21.30	30.12	25.96	0.0	0.002
14	24.72	21.11	25.95	22.86	21.33	30.12	30.33	0.0	0.002
16	24.70	20.96	25.97	22.78	21.30	30.12	31.71	0.0	0.002
18	24.74	21.03	25.96	22.81	21.31	30.58	30.25	0.0	0.002
20	24.83	21.03	26.03	22.84	21.37	30.58	31.98	0.0	0.002
22	24.90	20.99	25.99	22.77	21.31	30.58	30.48	0.0	0.002
24	24.91	20.94	26.05	22.72	21.33	34.85	26.89	0.0	0.002
26	24.92	20.89	26.16	22.76	21.42	34.85	30.29	0.0	0.002
28	24.93	20.83	26.11	22.69	21.35	34.85	28.57	0.0	0.002
30	24.94	20.78	26.08	22.65	21.31	34.85	29.05	0.0	0.002
32	24.94	20.73	26.08	22.62	21.30	34.85	29.44	0.0	0.002
34	24.95	20.68	26.08	22.58	21.28	34.85	29.58	0.0	0.002
36	24.96	20.62	25.88	22.48	21.10	30.12	31.16	0.0	0.002
38	24.97	20.57	25.84	22.44	21.05	30.12	32.05	0.0	0.002
40	24.98	20.52	25.85	22.41	21.04	30.12	32.77	0.0	0.002
42	24.99	20.46	25.85	22.37	21.03	30.58	33.20	0.0	0.002
44	24.99	20.44	25.84	22.35	21.01	30.58	32.90	0.0	0.002
46	25.00	20.46	25.69	22.26	20.87	30.58	27.99	0.0	0.002
48	25.01	20.41	25.84	22.28	20.97	34.85	28.45	0.0	0.002
50	25.05	20.48	26.09	22.47	21.23	34.85	34.13	0.0	0.002
52	25.02	20.42	26.05	22.41	21.18	34.85	32.41	0.0	0.002
54	24.99	20.42	26.03	22.41	21.16	34.85	32.80	0.0	0.002
56	24.97	20.46	26.09	22.47	21.23	34.85	33.78	0.0	0.002
58	24.96	20.36	25.96	22.32	21.08	34.85	30.40	0.0	0.002
60	24.95	20.32	25.62	22.15	20.77	30.12	28.32	0.0	0.002
62	24.96	20.37	25.57	22.15	20.73	30.12	28.13	0.0	0.002
64	24.99	20.43	25.60	22.20	20.78	30.12	27.89	0.0	0.002
66	25.00	20.40	25.61	22.18	20.78	30.58	28.26	0.0	0.002
68	25.00	20.40	25.79	22.31	20.96	30.58	34.47	0.0	0.002
70	24.99	20.45	25.83	22.36	21.01	30.58	33.35	0.0	0.002
72	24.98	20.42	26.02	22.40	21.15	34.85	33.62	0.0	0.002
74	24.96	20.40	25.95	22.35	21.08	34.85	30.30	0.0	0.002
76	24.95	20.40	25.90	22.32	21.04	34.85	29.98	0.0	0.002
78	24.94	20.33	25.99	22.34	21.10	34.85	33.50	0.0	0.002
80	24.92	20.37	26.00	22.37	21.13	34.85	32.99	0.0	0.002
82	24.91	20.30	26.06	22.37	21.16	34.85	35.59	0.0	0.003
84	24.90	20.26	25.75	22.21	20.88	30.12	33.27	0.0	0.002
86	24.88	20.27	25.65	22.17	20.80	30.12	32.32	0.0	0.002
88	24.86	20.25	25.60	22.12	20.74	30.12	31.05	0.0	0.002
90	24.81	20.17	24.67	20.47	19.37	0.0	0.0	0.0	0.000
92	24.77	20.08	24.43	20.29	19.13	0.0	0.0	0.0	0.000
94	24.73	20.14	24.42	20.36	19.15	0.0	0.0	0.0	0.000
96	24.70	20.05	24.38	20.26	19.08	0.0	0.0	0.0	0.000
98	24.69	20.03	24.36	20.24	19.06	0.0	0.0	0.0	0.000
100	24.69	20.02	24.34	20.22	19.04	0.0	0.0	0.0	0.000
102	24.68	20.00	24.34	20.20	19.03	0.0	0.0	0.0	0.000
104	24.68	19.98	24.32	20.18	19.01	0.0	0.0	0.0	0.000
106	24.67	19.97	24.31	20.17	19.00	0.0	0.0	0.0	0.000
108	24.66	19.95	24.29	20.14	18.97	0.0	0.0	0.0	0.000
110	24.65	19.96	24.28	20.15	18.97	0.0	0.0	0.0	0.000
112	24.64	19.98	24.28	20.17	18.97	0.0	0.0	0.0	0.000
114	24.63	19.94	24.27	20.14	18.95	0.0	0.0	0.0	0.000
116	24.62	19.92	24.26	20.12	18.94	0.0	0.0	0.0	0.000
118	24.61	19.95	24.26	20.15	18.95	0.0	0.0	0.0	0.000
120	24.61	19.95	24.25	20.14	18.94	0.0	0.0	0.0	0.000
122	24.60	19.96	24.24	20.15	18.94	0.0	0.0	0.0	0.000
124	24.59	19.97	24.24	20.16	18.94	0.0	0.0	0.0	0.000
126	24.58	19.97	24.22	20.16	18.93	0.0	0.0	0.0	0.000

128	24.57	19.98	24.20	20.16	18.92	0.0	0.0	0.0	0.000
130	24.57	19.98	24.19	20.16	18.91	0.0	0.0	0.0	0.000
132	24.57	19.97	24.19	20.15	18.90	0.0	0.0	0.0	0.000
134	24.60	19.96	24.20	20.13	18.90	0.0	0.0	0.0	0.000
136	24.65	20.07	24.23	20.23	18.97	0.0	0.0	0.0	0.000
138	24.68	20.20	25.63	22.16	20.78	30.58	40.90	0.0	0.002
140	24.65	20.14	25.71	22.16	20.83	30.58	36.42	0.0	0.002
142	24.65	20.13	25.64	22.11	20.76	30.58	36.61	0.0	0.002
144	24.76	20.24	25.98	22.31	21.08	34.85	37.90	0.0	0.002
146	24.79	20.19	25.82	22.16	20.91	34.85	30.69	0.0	0.002
148	24.76	20.22	25.96	22.29	21.06	34.85	36.98	0.0	0.002
150	24.70	20.16	25.96	22.25	21.04	34.85	35.32	0.0	0.002
152	24.71	20.15	25.78	22.13	20.87	34.85	30.63	0.0	0.002
154	24.72	20.16	25.97	22.27	21.06	34.85	37.93	0.0	0.003
156	24.76	20.24	25.67	22.16	20.81	30.12	32.12	0.0	0.002
158	24.80	20.29	25.58	22.14	20.74	30.12	31.80	0.0	0.002
160	24.84	20.32	25.62	22.18	20.79	30.12	32.06	0.0	0.002
162	24.90	20.38	25.65	22.22	20.82	30.58	31.61	0.0	0.002
164	24.97	20.64	25.63	22.34	20.87	30.58	26.98	0.0	0.002
166	24.97	21.11	25.88	22.78	21.24	30.58	29.20	0.0	0.002

A3.1.3 Maingate of the Advancing Face for the First Week

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	2
No. of sections	:	5
Type of ventilation	:	1
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	0.95	m/s
Initial virgin strata temperature	:	26.00	C
Geothermal gradient	:	0.04	C/m
Initial depth	:	1850.00	m
Final depth	:	1850.00	m
Length of airway	:	500.00	m
X sectional area	:	10.40	m^2
Advance rate	:	0.08	m/hr
Initial age of the airway	:	0.62E+04	hr
Average wetness factor	:	0.05	
Thermal conductivity of rock	:	2.69	W/m C

Input Data of Conveyed Coal

Velocity of conveyed belt	:	2.35	m/s
Width of conveyed belt	:	1.07	m
Length of conveyed belt	:	500.00	m
Number of shifts	:	4.00	
Roughness of conveyed coal	:	0.02	m
Density of conveyed coal	:	1350.00	Kg/m^3

Specific of heat capacity of coal	:	1130.00	J/Kg K
Thermal conductivity of coal	:	0.70	W/m K
Initial wetness factor of coal	:	0.40	
Final wetness factor of coal	:	0.30	
Initial temperature of coal	:	28.50	C
Roller radius of conveyed belt	:	127.00	mm
Running time	:	15.00	hr
% of conveyor power assumed	:	1.00	
Average tonnage over all shifts	:	0.66E+02	ton/hr

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg
0	27.83	22.77	27.66	25.66	23.46	41.23	77.80	0.0	0.005
2	27.95	22.95	27.55	25.57	23.34	41.23	80.30	0.0	0.004
4	27.87	23.16	27.63	25.74	23.49	41.23	81.38	0.0	0.004
6	27.62	22.77	27.87	23.98	22.67	33.23	0.0	0.0	0.002
8	27.55	22.65	27.55	23.71	22.32	33.23	0.0	0.0	0.002
10	27.69	22.84	27.55	23.79	22.36	33.23	0.0	0.0	0.002
12	27.74	22.79	27.36	25.35	23.09	41.23	89.38	0.0	0.004
14	27.78	22.82	27.45	25.44	23.20	41.23	87.77	0.0	0.004
16	27.74	22.80	27.45	25.35	23.15	41.23	89.04	0.0	0.004
18	27.88	22.93	27.49	25.51	23.27	41.23	86.04	0.0	0.004
20	27.90	23.06	27.49	25.46	23.24	41.23	83.91	0.0	0.004
22	28.00	23.17	27.54	25.66	23.39	41.23	80.96	0.0	0.004
24	28.78	23.66	27.49	25.73	23.40	41.23	69.83	0.0	0.004
26	29.27	23.91	27.51	25.83	23.47	41.23	65.70	0.0	0.004
28	29.43	24.06	27.55	25.91	23.54	41.23	63.66	0.0	0.004
30	29.25	23.79	28.11	24.79	23.25	33.23	0.0	0.0	0.002
32	29.75	24.04	27.95	24.67	23.09	33.23	0.0	0.0	0.002
34	30.09	24.25	28.11	24.83	23.28	33.23	0.0	0.0	0.002
36	30.32	24.40	27.45	25.88	23.46	41.23	58.40	0.0	0.004
38	30.56	24.38	27.41	23.98	22.37	0.0	0.0	0.0	0.001
40	30.59	24.32	27.46	25.86	23.45	41.23	54.72	0.0	0.004
42	30.55	24.30	27.37	25.85	23.39	41.23	53.29	0.0	0.004
44	30.86	24.45	27.37	25.89	23.41	41.23	50.52	0.0	0.004
46	29.08	23.65	27.42	25.76	23.37	41.23	68.39	0.0	0.004
48	29.11	23.53	27.39	25.66	23.29	41.23	72.36	0.0	0.004
50	30.28	24.11	27.24	23.75	22.14	0.0	0.0	0.0	0.001
52	30.59	24.53	27.39	24.09	22.42	0.0	0.0	0.0	0.001
54	30.45	24.37	27.46	25.91	23.48	41.23	53.01	0.0	0.004
56	30.91	24.70	27.40	26.00	23.50	41.23	45.63	0.0	0.004
58	31.18	24.97	27.49	26.17	23.66	41.23	43.91	0.0	0.004
60	31.24	24.89	27.49	26.14	23.64	41.23	44.61	0.0	0.004
62	31.29	24.71	27.76	24.21	22.72	0.0	0.0	0.0	0.001
64	31.04	24.47	27.69	24.06	22.59	0.0	0.0	0.0	0.001
66	31.04	24.40	27.65	23.97	22.52	0.0	0.0	0.0	0.001
68	31.13	24.41	27.68	23.97	22.54	0.0	0.0	0.0	0.001
70	31.36	24.55	27.76	24.06	22.63	0.0	0.0	0.0	0.001
72	30.95	24.32	27.67	23.95	22.52	0.0	0.0	0.0	0.001
74	31.09	24.23	27.65	23.82	22.44	0.0	0.0	0.0	0.001
76	31.16	24.21	27.75	23.68	22.43	0.0	0.0	0.0	0.001
78	31.15	24.19	27.85	23.64	22.47	0.0	0.0	0.0	0.001
80	31.17	24.17	27.94	23.58	22.50	0.0	0.0	0.0	0.000
82	31.19	24.15	28.06	23.52	22.55	0.0	0.0	0.0	0.000
84	31.16	24.11	28.13	23.52	22.59	0.0	0.0	0.0	0.000
86	31.10	24.06	28.14	23.50	22.59	0.0	0.0	0.0	0.000
88	31.04	24.00	28.15	23.47	22.58	0.0	0.0	0.0	0.000
90	30.99	23.93	28.20	23.34	22.54	0.0	0.0	0.0	0.000
92	30.93	23.91	28.33	23.20	22.56	0.0	0.0	0.0	0.000
94	30.87	23.92	28.48	23.19	22.64	0.0	0.0	0.0	-0.000
96	30.85	23.98	28.12	23.93	22.80	0.0	0.0	0.0	0.001
98	30.91	24.03	27.82	23.71	22.50	0.0	0.0	0.0	0.001
100	30.99	24.01	27.89	23.63	22.50	0.0	0.0	0.0	0.001
102	31.05	24.01	27.96	23.56	22.50	0.0	0.0	0.0	0.001
104	31.09	23.89	28.03	23.39	22.46	0.0	0.0	0.0	0.001

106	31.09	23.95	28.16	23.32	22.51	0.0	0.0	0.0	0.000
108	31.06	23.96	27.55	25.55	23.33	41.23	58.20	0.0	0.004
110	31.03	24.35	27.38	25.69	23.30	41.23	47.60	0.0	0.004
112	30.93	24.77	27.47	25.96	23.52	41.23	42.56	0.0	0.004
114	31.11	24.96	27.50	26.05	23.59	41.23	38.80	0.0	0.003
116	31.24	25.07	27.62	26.36	23.86	41.23	37.42	0.0	0.004
118	31.31	25.21	27.63	26.37	23.87	41.23	37.48	0.0	0.004
120	31.53	25.48	27.62	26.44	23.91	41.23	29.19	0.0	0.003
122	31.60	25.56	27.66	26.51	23.97	41.23	29.84	0.0	0.003
124	31.71	25.84	27.71	26.64	24.08	41.23	24.66	0.0	0.003
126	31.66	25.68	28.22	25.16	23.53	0.0	0.0	0.0	0.001
128	31.80	25.71	28.30	25.18	23.59	0.0	0.0	0.0	0.001
130	31.91	25.77	28.35	25.22	23.64	0.0	0.0	0.0	0.001
132	32.09	26.23	27.91	26.77	24.29	41.23	20.07	0.0	0.003
134	31.13	25.25	27.64	26.32	23.84	41.23	32.12	0.0	0.003
136	31.53	25.28	27.61	26.34	23.84	41.23	35.33	0.0	0.004
138	32.01	25.94	27.67	26.61	24.04	41.23	22.31	0.0	0.003
140	31.88	25.99	27.71	26.68	24.11	41.23	21.86	0.0	0.003
142	31.76	25.83	27.66	26.58	24.02	41.23	22.83	0.0	0.003
144	31.81	25.97	27.69	26.67	24.09	41.23	22.00	0.0	0.003
146	31.92	26.04	27.67	26.67	24.09	41.23	18.77	0.0	0.003
148	32.11	26.39	27.75	26.87	24.26	41.23	14.30	0.0	0.003
150	31.97	26.18	28.47	25.62	23.95	0.0	0.0	0.0	0.001
152	31.97	26.11	28.47	25.55	23.91	0.0	0.0	0.0	0.001
154	32.02	26.31	28.50	25.72	24.03	0.0	0.0	0.0	0.001
156	31.91	26.22	27.94	26.89	24.39	41.23	17.30	0.0	0.003
158	31.78	25.99	27.76	26.75	24.19	41.23	21.31	0.0	0.003
160	31.79	26.13	27.75	26.79	24.21	41.23	17.96	0.0	0.003
162	31.66	26.01	27.73	26.75	24.17	41.23	21.02	0.0	0.003
164	31.69	25.99	27.70	26.72	24.13	41.23	21.03	0.0	0.003
166	31.37	26.17	27.78	26.86	24.27	41.23	19.46	0.0	0.003

A3.1.4 Maingate of the Advancing Face for the Second Week

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	2
No. of sections	:	5
Type of ventilation	:	1
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	0.95	m/s
Initial virgin strata temperature	:	26.00	C
Geothermal gradient	:	0.04	C/m
Initial depth	:	1850.00	m
Final depth	:	1850.00	m
Length of airway	:	514.00	m
X sectional area	:	10.40	m^2
Advance rate	:	0.08	m/hr
Initial age of the airway	:	0.64E+04	hr
Average wetness factor	:	0.05	
Thermal conductivity of rock	:	2.69	W/m C

Input Data of Conveyed Coal

Velocity of conveyed belt	:	2.35	m/s
Width of conveyed belt	:	1.07	m
Length of conveyed belt	:	514.00	m
Number of shifts	:	4.00	
Roughness of conveyed coal	:	0.02	m
Density of conveyed coal	:	1350.00	Kg/m^3
Specific of heat capacity of coal	:	1130.00	J/Kg K
Thermal conductivity of coal	:	0.70	W/m K
Initial wetness factor of coal	:	0.15	
Final wetness factor of coal	:	0.10	
Initial temperature of coal	:	29.20	C
Roller radius of conveyed belt	:	127.00	mm
Running time	:	15.00	hr
% of conveyor power assumed	:	1.00	
Average tonnage over all shifts	:	0.66E+02	ton/hr

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg
0	31.98	26.14	28.92	26.47	24.73	41.87	-3.20	0.0	0.002
2	31.81	26.03	28.91	26.66	24.84	41.87	0.95	0.0	0.002
4	32.01	26.11	28.92	26.42	24.70	41.87	1.54	0.0	0.002
6	31.85	25.91	28.83	26.89	24.94	41.87	0.83	0.0	0.003
8	31.71	25.80	28.76	26.49	24.65	41.87	9.60	0.0	0.003
10	31.65	25.85	28.74	26.49	24.63	41.87	4.08	0.0	0.002
12	31.76	25.82	28.80	26.33	24.57	41.87	6.84	0.0	0.002
14	31.77	26.18	28.88	26.48	24.72	41.87	1.90	0.0	0.002
16	31.67	25.92	28.83	26.56	24.73	41.87	1.36	0.0	0.002
18	31.79	26.09	28.85	26.33	24.60	41.87	2.12	0.0	0.002
20	31.70	26.14	28.87	26.67	24.82	41.87	-2.22	0.0	0.002
22	31.71	26.15	28.87	26.58	24.77	41.87	1.49	0.0	0.002
24	32.05	26.28	28.89	26.51	24.74	41.87	-2.71	0.0	0.002
26	31.75	26.28	28.92	26.81	24.94	41.87	-1.52	0.0	0.002
28	31.76	26.15	28.89	26.68	24.85	41.87	3.17	0.0	0.002
30	31.91	26.17	28.18	26.08	24.04	0.0	0.0	0.0	0.001
32	31.96	26.09	28.29	25.46	23.75	0.0	0.0	0.0	0.001
34	31.81	26.14	28.20	26.12	24.08	0.0	0.0	0.0	0.002
36	31.79	26.07	28.77	26.10	24.41	41.87	2.00	0.0	0.001
38	31.60	25.96	28.86	26.16	24.50	41.87	-2.56	0.0	0.002
40	31.55	26.04	28.91	26.24	24.58	41.87	-1.06	0.0	0.002
42	31.63	25.98	28.61	25.63	24.04	0.0	0.0	0.0	0.001
44	31.58	26.13	28.48	25.70	24.00	0.0	0.0	0.0	0.001
46	31.76	26.27	28.54	25.80	24.10	0.0	0.0	0.0	0.001
48	31.75	26.09	28.95	26.40	24.71	41.87	0.77	0.0	0.002
50	31.70	26.14	28.88	26.42	24.67	41.87	-2.44	0.0	0.002
52	31.67	26.24	28.93	26.52	24.77	41.87	-0.98	0.0	0.002
54	31.78	26.19	28.90	26.45	24.71	41.87	-2.76	0.0	0.002
56	31.80	26.17	28.89	26.44	24.69	41.87	-2.81	0.0	0.002
58	31.58	26.01	28.88	26.36	24.64	41.87	-1.03	0.0	0.002
60	31.70	26.00	28.83	26.84	24.91	41.87	1.60	0.0	0.003
62	31.40	25.62	28.76	26.56	24.69	41.87	12.35	0.0	0.003
64	31.10	25.18	28.63	26.31	24.46	41.87	15.02	0.0	0.003
66	30.36	24.39	28.47	25.50	23.88	33.74	0.0	0.0	0.003
68	29.37	23.94	27.91	25.07	23.28	33.74	0.0	0.0	0.003
70	29.69	24.37	28.49	24.37	23.26	33.74	0.0	0.0	0.001
72	30.32	24.68	27.69	24.47	22.81	0.0	0.0	0.0	0.001
74	30.65	24.74	27.63	24.39	22.74	0.0	0.0	0.0	0.001
76	30.73	24.65	27.71	24.33	22.75	0.0	0.0	0.0	0.001
78	30.60	24.47	27.18	24.91	22.72	0.0	0.0	0.0	0.002
80	30.38	24.25	26.68	24.46	22.14	0.0	0.0	0.0	0.002
82	30.16	24.02	26.52	24.28	21.94	0.0	0.0	0.0	0.002

84	29.94	23.80	27.51	24.96	22.97	33.74	0.0	0.0	0.003
86	29.72	23.57	27.23	24.78	22.69	33.74	0.0	0.0	0.003
88	29.50	23.35	27.07	24.50	22.43	33.74	0.0	0.0	0.003
90	29.28	23.12	26.81	24.53	22.27	33.74	0.0	0.0	0.003
92	29.16	23.25	26.64	24.42	22.09	33.74	0.0	0.0	0.003
94	30.08	24.23	27.35	24.46	22.59	33.74	0.0	0.0	0.002
96	30.63	24.44	26.45	24.50	22.00	0.0	0.0	0.0	0.002
98	30.72	24.36	26.45	24.10	21.79	0.0	0.0	0.0	0.001
100	30.70	24.29	26.58	24.17	21.92	0.0	0.0	0.0	0.002
102	30.65	24.22	26.55	24.11	21.87	0.0	0.0	0.0	0.002
104	30.60	24.14	27.79	24.80	23.06	33.74	0.0	0.0	0.002
106	30.55	24.07	27.63	24.91	23.02	33.74	0.0	0.0	0.003
108	30.50	23.99	27.50	24.77	22.86	33.74	0.0	0.0	0.003
110	30.74	24.84	27.75	25.25	23.28	33.74	0.0	0.0	0.002
112	30.91	25.14	28.11	25.42	23.61	33.74	0.0	0.0	0.002
114	31.22	25.46	28.36	25.68	23.92	41.87	16.78	0.0	0.002
116	31.26	25.68	28.52	25.96	24.18	41.87	8.47	0.0	0.002
118	31.34	25.64	28.57	25.94	24.20	41.87	8.41	0.0	0.002
120	31.35	25.66	27.97	25.13	23.35	0.0	0.0	0.0	0.001
122	31.28	25.55	27.90	25.02	23.25	0.0	0.0	0.0	0.001
124	31.38	25.71	27.96	25.16	23.36	0.0	0.0	0.0	0.001
126	31.38	25.57	28.67	25.94	24.26	41.87	8.59	0.0	0.002
128	31.18	25.75	28.73	26.14	24.42	41.87	7.70	0.0	0.002
130	31.12	25.56	28.73	26.02	24.34	41.87	8.36	0.0	0.002
132	31.13	25.61	28.76	26.07	24.39	41.87	9.09	0.0	0.002
134	31.07	25.56	28.78	26.06	24.40	41.87	9.66	0.0	0.002
136	31.26	25.93	28.86	26.31	24.59	41.87	7.40	0.0	0.002
138	31.18	25.75	28.88	26.22	24.55	41.87	8.38	0.0	0.002
140	31.23	25.92	28.84	26.30	24.58	41.87	4.12	0.0	0.002
142	31.20	25.90	28.86	26.31	24.60	41.87	5.07	0.0	0.002
144	31.30	25.80	28.85	26.22	24.54	41.87	4.60	0.0	0.002
146	30.85	25.56	28.87	26.15	24.51	41.87	8.66	0.0	0.002
148	31.10	25.81	28.90	26.28	24.60	41.87	6.19	0.0	0.002
150	31.18	25.88	28.35	25.54	23.83	0.0	0.0	0.0	0.001
152	31.10	25.84	28.24	25.48	23.73	0.0	0.0	0.0	0.001
154	30.98	25.68	28.19	25.36	23.62	0.0	0.0	0.0	0.001
156	31.16	25.66	28.89	26.15	24.52	41.87	8.28	0.0	0.002
158	30.82	25.65	28.94	26.25	24.60	41.87	8.80	0.0	0.002
160	30.95	25.79	28.99	26.34	24.69	41.87	8.33	0.0	0.002
162	31.15	25.80	28.97	26.31	24.66	41.87	4.85	0.0	0.002
164	31.37	26.17	29.06	26.56	24.87	41.87	2.89	0.0	0.002
166	31.67	26.15	29.04	26.50	24.82	41.87	-1.17	0.0	0.002

A3.1.5 Tailgate of the Advancing Face for the First Week

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	1
No. of sections	:	5
Type of ventilation	:	0
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	1.19	m/s
Initial virgin strata temperature	:	26.00	C
Geothermal gradient	:	0.04	C/m
Initial depth	:	1850.00	m
Final depth	:	1850.00	m
Length of airway	:	500.00	m
X sectional area	:	9.45	m^2
Advance rate	:	0.08	m/hr
Initial age of the airway	:	0.17E+03	hr
Average wetness factor	:	0.05	
Thermal conductivity of rock	:	2.69	W/m C

Input Data of Conveyed Coal

Velocity of conveyed belt	:	2.35	m/s
Width of conveyed belt	:	1.07	m
Length of conveyed belt	:	500.00	m
Number of shifts	:	4.00	
Roughness of conveyed coal	:	0.02	m
Density of conveyed coal	:	1350.00	Kg/m^3
Specific of heat capacity of coal	:	1130.00	J/Kg K
Thermal conductivity of coal	:	0.70	W/m K
Initial wetness factor of coal	:	0.60	
Final wetness factor of coal	:	0.50	
Initial temperature of coal	:	29.00	C
Roller radius of conveyed belt	:	127.00	mm
Running time	:	15.00	hr
% of conveyor power assumed	:	1.00	
Average tonnage over all shifts	:	0.11E+01	ton/hr

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg
0	27.69	26.39	27.85	26.72	23.73	29.66	5.39	0.0	0.001
2	27.52	25.82	27.88	26.58	23.67	29.66	8.93	0.0	0.001
4	27.59	26.42	27.92	26.80	23.83	29.66	6.02	0.0	0.001
6	27.74	26.51	28.21	26.83	24.05	29.66	6.32	0.0	0.000
8	27.43	26.20	28.01	26.70	23.83	29.66	1.81	0.0	0.001
10	27.50	26.24	27.94	26.71	23.79	29.66	6.50	0.0	0.001
12	28.14	26.63	28.25	26.87	24.11	29.66	7.45	0.0	0.000
14	28.77	26.31	28.21	26.84	24.05	29.66	6.53	0.0	0.001
16	28.53	25.45	27.58	26.42	23.36	29.66	6.42	0.0	0.002
18	27.66	24.17	26.81	25.55	22.29	29.66	13.96	0.0	0.003
20	28.42	25.90	27.38	26.33	23.17	29.66	15.07	0.0	0.001
22	27.68	24.48	27.06	25.84	22.64	29.66	12.33	0.0	0.003
24	27.78	25.92	27.24	26.29	23.04	29.66	9.81	0.0	0.001
26	27.68	26.33	27.77	26.73	23.68	29.66	5.62	0.0	0.001
28	27.53	26.35	27.91	26.78	23.81	29.66	10.05	0.0	0.001
30	27.64	26.50	28.05	26.93	24.00	29.66	8.76	0.0	0.001
32	27.69	26.46	28.07	26.89	23.99	29.66	7.77	0.0	0.001
34	27.82	26.70	28.20	27.10	24.21	29.66	8.33	0.0	0.001
36	28.36	26.78	28.44	27.05	24.34	29.66	10.84	0.0	0.000
38	28.43	25.99	28.13	26.84	24.00	29.66	12.08	0.0	0.002
40	27.73	25.42	27.47	26.33	23.23	29.66	10.28	0.0	0.002
42	27.85	26.43	27.79	26.77	23.73	29.66	6.83	0.0	0.001
44	28.80	26.40	28.07	26.78	23.92	29.66	5.47	0.0	0.001
46	29.45	26.29	28.03	26.58	23.77	29.66	2.71	0.0	0.001
48	27.61	24.09	27.01	25.72	22.54	29.66	11.35	0.0	0.003
50	27.71	26.22	27.30	26.40	23.15	29.66	7.31	0.0	0.001
52	27.70	25.85	27.83	26.77	23.75	29.66	18.65	0.0	0.002

54	27.79	26.38	27.84	26.81	23.78	29.66	13.05	0.0	0.001
56	27.58	26.20	27.80	26.69	23.68	29.66	4.32	0.0	0.001
58	27.54	26.19	27.83	26.75	23.74	29.66	12.24	0.0	0.001
60	28.07	26.33	27.87	26.72	23.75	29.66	5.30	0.0	0.001
62	28.59	26.06	27.86	26.51	23.61	29.66	7.78	0.0	0.001
64	27.62	24.68	27.14	25.85	22.71	29.66	9.89	0.0	0.002
66	28.09	25.93	27.27	26.12	22.96	29.66	3.44	0.0	0.001
68	28.25	25.27	27.42	26.05	23.03	29.66	10.29	0.0	0.002
70	27.52	24.29	26.80	25.32	22.16	29.66	12.34	0.0	0.002
72	27.83	25.87	27.30	26.20	23.03	29.66	10.71	0.0	0.001
74	28.12	25.33	27.37	25.88	22.89	29.66	5.51	0.0	0.001
76	28.23	24.98	27.10	25.70	22.60	29.66	8.86	0.0	0.002
78	28.27	24.82	27.00	25.56	22.44	29.66	10.80	0.0	0.002
80	28.26	24.67	26.92	25.45	22.32	29.66	11.70	0.0	0.002
82	28.23	24.56	26.87	25.38	22.24	29.66	13.91	0.0	0.002
84	28.21	24.47	26.74	25.38	22.14	29.66	11.03	0.0	0.002
86	28.18	24.38	26.59	25.23	21.95	29.66	10.66	0.0	0.002
88	28.13	24.28	26.49	25.12	21.81	29.66	9.10	0.0	0.002
90	27.89	24.04	26.33	24.94	21.60	29.66	9.88	0.0	0.002
92	27.63	23.80	26.15	24.76	21.37	29.66	10.87	0.0	0.002
94	27.56	23.73	26.04	24.77	21.29	29.66	11.04	0.0	0.002
96	27.75	25.09	26.53	25.37	21.98	29.66	6.69	0.0	0.001
98	27.78	24.60	26.72	25.33	22.10	29.66	9.48	0.0	0.002
100	27.80	24.43	26.50	25.09	21.81	29.66	7.62	0.0	0.002
102	27.83	24.29	26.55	25.09	21.85	29.66	13.53	0.0	0.002
104	27.78	24.15	26.44	24.94	21.68	29.66	9.79	0.0	0.002
106	27.65	23.98	26.28	24.92	21.54	29.66	9.85	0.0	0.002
108	27.52	23.82	26.19	24.82	21.43	29.66	15.26	0.0	0.002
110	27.39	23.65	26.02	24.63	21.20	29.66	11.09	0.0	0.002
112	27.28	24.49	26.24	25.08	21.60	29.66	6.98	0.0	0.001
114	27.41	25.97	27.20	26.31	23.02	29.66	16.38	0.0	0.001
116	26.97	25.54	27.32	26.18	23.03	29.66	14.91	0.0	0.001
118	27.59	26.27	27.57	26.54	23.43	29.66	11.67	0.0	0.001
120	26.93	25.74	27.49	26.24	23.19	29.66	7.03	0.0	0.001
122	27.19	26.34	27.63	26.66	23.55	29.66	6.63	0.0	0.000
124	27.23	26.37	27.86	26.71	23.73	29.66	9.36	0.0	0.000
126	27.94	26.47	28.07	26.73	23.89	29.66	10.23	0.0	0.000
128	28.48	26.30	28.08	26.81	23.95	29.66	12.39	0.0	0.001
130	28.74	25.96	27.86	26.45	23.58	29.66	10.94	0.0	0.001
132	28.99	25.81	27.77	26.42	23.50	29.66	11.57	0.0	0.002
134	27.60	24.35	27.20	25.11	22.33	29.66	12.90	0.0	0.001
136	28.27	26.81	27.99	27.08	24.06	29.66	9.41	0.0	0.001
138	29.04	26.63	28.26	26.81	24.07	29.66	4.61	0.0	0.001
140	27.95	25.25	27.65	26.07	23.20	29.66	9.14	0.0	0.002
142	27.53	26.30	27.74	26.72	23.65	29.66	7.76	0.0	0.001
144	27.62	26.49	28.08	26.76	23.92	29.66	4.87	0.0	0.000
146	27.96	26.90	28.46	27.23	24.47	29.66	10.11	0.0	0.000
148	28.05	27.09	28.56	27.35	24.62	29.66	5.26	0.0	0.000
150	28.30	26.95	28.59	27.20	24.54	29.66	5.34	0.0	0.000
152	28.79	26.58	28.63	26.84	24.34	29.66	8.76	0.0	0.001
154	29.36	26.50	28.65	26.60	24.20	29.66	3.59	0.0	0.001
156	29.82	26.75	28.95	26.91	24.59	29.66	11.51	0.0	0.001
158	29.91	26.51	28.75	26.84	24.42	29.66	3.68	0.0	0.001
160	29.94	26.38	28.50	26.61	24.11	29.66	1.46	0.0	0.001
162	30.22	26.71	28.79	26.99	24.54	29.66	10.19	0.0	0.001
164	29.67	26.01	28.60	26.55	24.13	29.66	12.00	0.0	0.001
166	28.29	25.44	27.85	26.42	23.55	29.66	3.62	0.0	0.002

A3.1.6 Tailgate of the Advancing Face for the Second Week

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	1
No. of sections	:	5
Type of ventilation	:	0
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	1.19	m/s
Initial virgin strata temperature	:	26.00	C
Geothermal gradient	:	0.04	C/m
Initial depth	:	1850.00	m
Final depth	:	1850.00	m
Length of airway	:	514.00	m
X sectional area	:	9.45	m^2
Advance rate	:	0.08	m/hr
Initial age of the airway	:	0.64E+04	hr
Average wetness factor	:	0.05	
Thermal conductivity of rock	:	2.69	W/m C

Input Data of Conveyed Coal

Velocity of conveyed belt	:	2.35	m/s
Width of conveyed belt	:	1.07	m
Length of conveyed belt	:	514.00	m
Number of shifts	:	-4.00	
Roughness of conveyed coal	:	0.02	m
Density of conveyed coal	:	1350.00	Kg/m^3
Specific of heat capacity of coal	:	1130.00	J/Kg K
Thermal conductivity of coal	:	0.70	W/m K
Initial wetness factor of coal	:	0.50	
Final wetness factor of coal	:	0.30	
Initial temperature of coal	:	29.50	C
Roller radius of conveyed belt	:	127.00	mm
Running time	:	15.00	hr
% of conveyor power assumed	:	1.00	
Average tonnage over all shifts	:	0.15E+01	ton/hr

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg
0	27.58	26.52	28.42	27.12	24.38	30.18	13.54	0.0	0.001
2	27.80	26.78	28.47	27.24	24.48	30.18	8.83	0.0	0.001
4	27.47	26.41	28.33	27.00	24.24	30.18	10.73	0.0	0.001
6	28.35	26.77	28.41	27.07	24.34	30.18	3.84	0.0	0.001
8	29.12	26.62	28.67	26.99	24.46	30.18	9.18	0.0	0.001
10	29.56	26.36	28.77	26.83	24.42	30.18	15.01	0.0	0.001
12	28.00	24.59	27.98	25.54	23.12	30.18	18.11	0.0	0.001
14	29.35	26.81	28.43	26.95	24.27	30.18	5.69	0.0	0.002
16	29.39	26.15	28.68	26.64	24.25	30.18	9.46	0.0	0.001
									0.001

18	28.72	25.09	28.15	25.80	23.39	30.18	15.11	0.0	0.001
20	28.37	25.98	28.29	26.56	23.94	30.18	15.70	0.0	0.001
22	27.78	26.35	28.36	26.91	24.20	30.18	9.98	0.0	0.001
24	27.42	26.54	28.25	27.03	24.21	30.18	6.21	0.0	0.001
26	27.54	26.64	28.31	27.11	24.29	30.18	7.18	0.0	0.001
28	27.66	26.74	28.37	27.18	24.38	30.18	6.80	0.0	0.001
30	27.85	26.53	28.37	27.02	24.28	30.18	9.61	0.0	0.001
32	28.28	26.30	28.39	26.81	24.16	30.18	12.19	0.0	0.001
34	28.67	26.15	28.35	26.59	23.99	30.18	8.28	0.0	0.001
36	28.11	25.96	28.24	26.53	23.88	30.18	10.10	0.0	0.001
38	27.84	26.70	28.38	27.15	24.37	30.18	8.16	0.0	0.001
40	27.88	26.77	28.50	27.25	24.51	30.18	9.26	0.0	0.001
42	27.64	26.00	28.18	26.61	23.90	30.18	10.16	0.0	0.001
44	27.56	26.19	28.09	26.70	23.89	30.18	8.69	0.0	0.001
46	27.93	26.13	28.20	26.68	23.95	30.18	12.96	0.0	0.001
48	28.01	26.84	28.45	27.26	24.49	30.18	10.10	0.0	0.001
50	27.78	26.70	28.41	27.16	24.39	30.18	6.35	0.0	0.001
52	27.63	26.59	28.31	27.08	24.27	30.18	8.29	0.0	0.001
54	27.88	26.46	28.30	26.93	24.17	30.18	8.17	0.0	0.001
56	28.22	26.14	28.23	26.61	23.93	30.18	8.33	0.0	0.001
58	28.55	25.97	28.28	26.49	23.89	30.18	12.89	0.0	0.001
60	28.78	26.02	28.35	26.52	23.95	30.18	12.32	0.0	0.001
62	28.80	25.73	28.26	26.26	23.73	30.18	11.43	0.0	0.001
64	28.54	25.39	28.19	26.11	23.60	30.18	19.95	0.0	0.001
66	28.73	25.60	28.16	26.14	23.60	30.18	12.64	0.0	0.001
68	28.66	25.46	28.11	26.03	23.50	30.18	11.64	0.0	0.001
70	28.05	25.56	28.07	26.20	23.57	30.18	12.97	0.0	0.001
72	28.24	25.73	28.18	26.36	23.74	30.18	16.76	0.0	0.001
74	28.28	25.33	28.03	25.98	23.41	30.18	13.07	0.0	0.001
76	28.26	25.25	28.01	25.96	23.39	30.18	18.09	0.0	0.001
78	28.25	25.19	27.84	25.76	23.16	30.18	9.09	0.0	0.001
80	28.23	25.14	27.77	25.70	23.07	30.18	9.11	0.0	0.001
82	28.21	25.08	27.84	25.74	23.14	30.18	14.52	0.0	0.001
84	28.20	25.02	27.80	25.67	23.08	30.18	13.59	0.0	0.001
86	28.18	24.97	27.77	25.63	23.03	30.18	13.60	0.0	0.001
88	28.16	24.91	27.79	25.62	23.03	30.18	16.32	0.0	0.001
90	28.17	24.86	27.68	25.50	22.89	30.18	12.19	0.0	0.001
92	28.14	24.75	27.66	25.44	22.85	30.18	14.71	0.0	0.001
94	27.27	23.88	27.25	24.83	22.22	30.18	16.93	0.0	0.002
96	26.67	25.04	27.39	25.78	22.85	30.18	15.07	0.0	0.001
98	26.54	25.10	27.49	25.89	22.99	30.18	14.34	0.0	0.001
100	26.45	24.98	27.42	25.80	22.88	30.18	15.85	0.0	0.001
102	26.36	24.93	27.31	25.71	22.75	30.18	13.04	0.0	0.001
104	26.28	24.84	27.21	25.61	22.62	30.18	11.90	0.0	0.001
106	26.38	24.86	27.32	25.69	22.75	30.18	17.74	0.0	0.001
108	26.66	24.69	27.22	25.44	22.54	30.18	12.98	0.0	0.001
110	26.74	25.17	27.37	25.82	22.86	30.18	11.29	0.0	0.001
112	26.74	25.42	27.56	26.09	23.14	30.18	12.19	0.0	0.001
114	27.24	25.60	27.65	26.13	23.24	30.18	8.13	0.0	0.001
116	27.32	26.09	27.96	26.62	23.75	30.18	10.15	0.0	0.001
118	27.33	26.14	28.00	26.64	23.78	30.18	5.58	0.0	0.001
120	27.06	25.48	27.84	26.23	23.43	30.18	14.85	0.0	0.001
122	26.87	25.61	27.78	26.31	23.43	30.18	13.77	0.0	0.001
124	26.75	25.50	27.69	26.18	23.29	30.18	10.28	0.0	0.001
126	26.79	25.60	27.75	26.30	23.41	30.18	14.23	0.0	0.001
128	27.02	25.88	27.85	26.46	23.58	30.18	8.99	0.0	0.001
130	27.77	26.13	28.13	26.65	23.88	30.18	11.49	0.0	0.001
132	27.90	26.27	28.28	26.78	24.06	30.18	8.64	0.0	0.001
134	28.58	26.12	28.42	26.64	24.08	30.18	12.93	0.0	0.001
136	27.89	26.55	28.50	27.09	24.41	30.18	10.10	0.0	0.001
138	28.04	26.32	28.45	26.88	24.25	30.18	10.69	0.0	0.001
140	27.91	26.75	28.55	27.24	24.54	30.18	8.84	0.0	0.001
142	27.95	26.70	28.65	27.27	24.62	30.18	12.53	0.0	0.001
144	27.69	26.50	28.50	27.10	24.42	30.18	11.24	0.0	0.001
146	27.62	26.52	28.46	27.11	24.39	30.18	11.59	0.0	0.001
148	27.60	26.33	28.46	27.01	24.33	30.18	15.82	0.0	0.001

150	27.66	25.74	28.21	26.46	23.82	30.18	14.11	0.0	0.001
152	28.65	26.13	28.37	26.59	24.01	30.18	10.00	0.0	0.001
154	29.21	26.26	28.65	26.72	24.27	30.18	10.74	0.0	0.001
156	29.44	26.10	28.61	26.53	24.13	30.18	7.27	0.0	0.001
158	29.34	25.83	28.61	26.41	24.06	30.18	14.40	0.0	0.001
160	29.34	25.81	28.53	26.32	23.95	30.18	9.81	0.0	0.001
162	29.82	26.36	28.85	26.80	24.46	30.18	13.80	0.0	0.001
164	28.25	26.57	28.78	27.17	24.64	30.18	8.81	0.0	0.001
166	28.12	26.37	28.48	26.87	24.26	30.18	5.54	0.0	0.001

A3.2 WHITEMOOR COLLIERY

A3.2.1 Maingate of the Retreating Face for the Second Week

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	0
No. of sections	:	5
Type of ventilation	:	1
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	2.31	m/s
Initial virgin strata temperature	:	38.30	C
Geothermal gradient	:	0.03	C/m
Initial depth	:	913.00	m
Final depth	:	913.00	m
Length of airway	:	480.00	m
X sectional area	:	12.40	m^2
Advance rate	:	0.38	m/hr
Initial age of the airway	:	0.40E+04	hr
Average wetness factor	:	0.05	
Thermal conductivity of rock	:	2.69	W/m C

Input Data of Conveyed Coal

Velocity of conveyed belt	:	2.35	m/s
Width of conveyed belt	:	1.07	m
Length of conveyed belt	:	500.00	m
Number of shifts	:	-4.00	
Roughness of conveyed coal	:	0.02	m
Density of conveyed coal	:	1350.00	Kg/m^3
Specific of heat capacity of coal	:	1130.00	J/Kg K
Thermal conductivity of coal	:	0.50	W/m K
Initial wetness factor of coal	:	0.30	
Final wetness factor of coal	:	0.30	
Initial temperature of coal	:	27.50	C
Roller radius of conveyed belt	:	127.00	mm

Running time	:	15.00 hr
% of conveyor power assumed	:	1.00
Average tonnage over all shifts	:	0.31E+03 ton/hr

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg
0	21.24	18.43	24.91	21.01	16.49	54.59	174.30	0.0	0.002
2	21.46	18.32	23.20	19.28	14.20	0.0	0.0	0.0	0.001
4	21.58	18.65	24.95	21.11	16.57	54.59	168.16	0.0	0.002
6	21.68	17.90	25.29	20.68	16.79	54.59	170.44	0.0	0.002
8	21.46	17.30	25.03	20.21	16.40	54.59	179.88	0.0	0.002
10	21.44	16.87	25.01	19.91	16.30	54.59	187.70	0.0	0.002
12	21.25	16.44	22.96	17.56	13.65	0.0	0.0	0.0	0.001
14	21.14	16.49	22.53	17.45	13.15	0.0	0.0	0.0	0.001
16	21.38	17.49	22.75	18.36	13.53	0.0	0.0	0.0	0.001
18	21.31	16.72	22.70	17.67	13.37	0.0	0.0	0.0	0.001
20	22.00	17.53	24.84	20.14	16.18	54.59	175.06	0.0	0.002
22	22.12	17.55	25.27	20.32	16.68	54.59	171.43	0.0	0.002
24	22.87	18.88	25.57	21.21	17.23	54.59	152.43	0.0	0.002
26	22.42	19.07	25.66	21.49	17.41	54.59	148.79	0.0	0.002
28	22.28	18.99	25.54	21.42	17.27	54.59	150.01	0.0	0.002
30	21.82	18.44	25.39	21.08	17.01	54.59	160.50	0.0	0.002
32	21.69	17.50	25.23	20.39	16.65	54.59	179.26	0.0	0.002
34	21.53	16.87	25.07	19.92	16.36	54.59	186.53	0.0	0.002
36	22.41	17.16	25.23	19.95	16.53	54.59	175.26	0.0	0.002
38	22.46	18.13	23.81	19.01	14.83	0.0	0.0	0.0	0.001
40	22.40	17.26	25.11	19.98	16.42	54.59	173.81	0.0	0.002
42	21.43	16.44	25.04	19.62	16.26	54.59	186.98	0.0	0.003
44	21.53	15.55	24.78	18.86	15.82	54.59	200.24	0.0	0.003
46	21.16	14.78	24.61	18.35	15.53	54.59	208.52	0.0	0.003
48	21.16	15.82	24.66	19.09	15.74	54.59	200.22	0.0	0.003
50	21.66	16.27	24.86	19.36	16.02	54.59	190.48	0.0	0.003
52	21.00	15.73	24.70	19.10	15.79	54.59	200.62	0.0	0.003
54	21.01	15.91	24.66	19.20	15.77	54.59	201.68	0.0	0.003
56	20.78	15.54	24.58	18.97	15.64	54.59	206.29	0.0	0.003
58	20.41	14.81	24.34	18.46	15.28	54.59	216.75	0.0	0.003
60	19.95	13.51	23.98	17.52	14.72	54.59	228.96	0.0	0.003
62	19.67	12.88	21.60	14.35	11.78	0.0	0.0	0.0	0.001
64	19.60	13.40	21.16	14.62	11.31	0.0	0.0	0.0	0.001
66	19.80	13.76	21.33	14.95	11.53	0.0	0.0	0.0	0.001
68	19.99	13.87	21.40	15.00	11.61	0.0	0.0	0.0	0.001
70	20.35	13.69	21.59	14.78	11.80	0.0	0.0	0.0	0.001
72	19.85	13.08	21.34	14.32	11.49	0.0	0.0	0.0	0.001
74	20.12	13.21	21.35	14.32	11.51	0.0	0.0	0.0	0.001
76	20.47	13.95	21.62	14.98	11.86	0.0	0.0	0.0	0.001
78	19.98	13.67	21.43	14.84	11.63	0.0	0.0	0.0	0.001
80	19.74	13.41	21.17	14.57	11.32	0.0	0.0	0.0	0.001
82	19.81	13.42	21.16	14.55	11.31	0.0	0.0	0.0	0.001
84	19.99	13.57	21.24	14.65	11.40	0.0	0.0	0.0	0.001
86	19.91	13.53	21.19	14.62	11.35	0.0	0.0	0.0	0.001
88	19.79	13.39	21.10	14.50	11.24	0.0	0.0	0.0	0.001
90	20.17	13.50	21.26	14.52	11.42	0.0	0.0	0.0	0.001
92	19.97	13.16	21.22	14.28	11.36	0.0	0.0	0.0	0.001
94	19.68	12.78	21.00	13.95	11.09	0.0	0.0	0.0	0.001
96	19.83	12.74	21.01	13.85	11.10	0.0	0.0	0.0	0.001
98	20.25	12.86	21.26	13.90	11.38	0.0	0.0	0.0	0.001
100	20.76	13.50	21.60	14.44	11.79	0.0	0.0	0.0	0.001
102	20.12	13.13	21.35	14.25	11.50	0.0	0.0	0.0	0.001
104	19.98	13.05	21.12	14.12	11.24	0.0	0.0	0.0	0.001
106	19.89	13.12	21.06	14.19	11.17	0.0	0.0	0.0	0.001
108	19.93	13.28	21.07	14.32	11.19	0.0	0.0	0.0	0.001
110	20.29	13.60	21.27	14.56	11.44	0.0	0.0	0.0	0.001

112	20.20	13.53	21.29	14.55	11.46	0.0	0.0	0.0	0.001
114	20.17	13.52	23.41	17.20	14.08	54.59	234.85	0.0	0.003
116	20.41	13.59	23.78	17.34	14.49	54.59	227.96	0.0	0.003
118	20.60	13.95	23.86	17.58	14.61	54.59	225.76	0.0	0.003
120	20.93	15.48	24.23	18.72	15.22	54.59	209.89	0.0	0.003
122	20.72	15.89	24.32	19.11	15.40	54.59	205.34	0.0	0.002
124	20.70	15.80	24.30	19.03	15.36	54.59	204.58	0.0	0.002
126	20.86	15.90	24.38	19.10	15.46	54.59	204.50	0.0	0.002
128	20.40	15.54	24.25	18.92	15.28	54.59	209.07	0.0	0.003
130	20.22	14.63	24.06	18.26	14.95	54.59	222.89	0.0	0.003
132	20.31	13.77	23.92	17.57	14.68	54.59	228.41	0.0	0.003
134	20.20	13.56	23.84	17.42	14.57	54.59	230.31	0.0	0.003
136	20.48	14.86	24.09	18.36	15.00	54.59	220.75	0.0	0.003
138	19.99	14.30	23.99	18.06	14.83	54.59	227.63	0.0	0.003
140	20.50	13.97	23.92	17.64	14.68	54.59	222.48	0.0	0.003
142	19.78	13.21	23.73	17.25	14.42	54.59	235.35	0.0	0.003
144	20.07	14.14	23.86	17.87	14.66	54.59	231.58	0.0	0.003
146	20.68	15.48	24.23	18.80	15.24	54.59	212.98	0.0	0.003
148	20.18	15.32	24.15	18.78	15.16	54.59	213.26	0.0	0.003
150	20.24	15.51	24.13	18.89	15.15	54.59	212.74	0.0	0.002
152	19.40	14.73	23.91	18.49	14.83	54.59	227.64	0.0	0.003
154	19.35	14.00	23.69	17.90	14.50	54.59	236.58	0.0	0.003
156	19.51	13.55	23.66	17.53	14.39	54.59	240.99	0.0	0.003
158	19.73	13.64	23.70	17.55	14.44	54.59	237.08	0.0	0.003
160	19.47	14.30	23.74	18.09	14.58	54.59	232.57	0.0	0.003
162	19.51	14.66	23.79	18.34	14.68	54.59	227.99	0.0	0.003
164	20.43	15.32	24.06	18.65	15.03	54.59	211.88	0.0	0.003
166	20.50	14.92	24.16	18.43	15.09	54.59	217.70	0.0	0.003

A3.2.2 Tailgate of the Retreating Face for the First Week

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	0
No. of sections	:	5
Type of ventilation	:	1
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	2.49	m/s
Initial virgin strata temperature	:	38.30	C
Geothermal gradient	:	0.03	C/m
Initial depth	:	913.00	m
Final depth	:	913.00	m
Length of airway	:	416.00	m
X sectional area	:	13.50	m^2
Advance rate	:	0.38	m/hr
Initial age of the airway	:	0.40E+04	hr
Average wetness factor	:	0.00	
Thermal conductivity of rock	:	2.69	W/m C

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg
0	29.82	27.85	30.61	28.07	24.74	0.0	0.0	0.0	0.000
2	29.71	27.13	30.51	27.37	24.22	0.0	0.0	0.0	0.000
4	29.45	27.06	30.32	27.32	24.03	0.0	0.0	0.0	0.000
6	29.24	26.88	30.14	27.15	23.79	0.0	0.0	0.0	0.000
8	28.84	25.79	29.86	26.11	22.96	0.0	0.0	0.0	0.000
10	29.30	25.87	30.06	26.11	23.13	0.0	0.0	0.0	0.000
12	29.27	26.30	30.14	26.57	23.45	0.0	0.0	0.0	0.000
14	28.91	26.15	29.90	26.45	23.18	0.0	0.0	0.0	0.000
16	28.16	25.88	29.37	26.24	22.62	0.0	0.0	0.0	0.000
18	27.69	24.98	28.92	25.37	21.78	0.0	0.0	0.0	0.000
20	27.46	24.28	28.68	24.67	21.23	0.0	0.0	0.0	0.000
22	27.44	23.96	28.59	24.34	21.00	0.0	0.0	0.0	0.000
24	27.70	23.98	28.73	24.32	21.11	0.0	0.0	0.0	0.000
26	28.63	24.86	29.33	25.09	21.99	0.0	0.0	0.0	0.000
28	28.20	26.24	29.25	26.55	22.70	0.0	0.0	0.0	0.000
30	28.83	27.52	29.54	27.72	23.64	0.0	0.0	0.0	0.000
32	28.57	26.70	29.54	26.98	23.19	0.0	0.0	0.0	0.000
34	28.10	25.59	29.17	25.92	22.27	0.0	0.0	0.0	0.000
36	28.55	25.44	29.35	25.69	22.31	0.0	0.0	0.0	0.000
38	28.81	27.21	29.60	27.44	23.52	0.0	0.0	0.0	0.000
40	28.81	27.56	29.64	27.79	23.77	0.0	0.0	0.0	0.000
42	28.71	27.41	29.58	27.66	23.64	0.0	0.0	0.0	0.000
44	28.03	26.35	29.15	26.68	22.68	0.0	0.0	0.0	0.000
46	28.83	27.82	29.51	28.01	23.79	0.0	0.0	0.0	0.000
48	28.99	28.05	29.79	28.27	24.20	0.0	0.0	0.0	0.000
50	29.22	28.18	29.93	28.37	24.39	0.0	0.0	0.0	0.000
52	29.35	28.60	30.07	28.79	24.80	0.0	0.0	0.0	0.000
54	29.65	29.08	30.28	29.25	25.29	0.0	0.0	0.0	0.000
56	29.70	28.84	30.37	29.02	25.20	0.0	0.0	0.0	0.000
58	29.51	27.97	30.26	28.18	24.53	0.0	0.0	0.0	0.000
60	29.07	26.86	29.95	27.12	23.61	0.0	0.0	0.0	0.000
62	28.92	26.21	29.76	26.47	23.07	0.0	0.0	0.0	0.000
64	29.30	27.98	29.97	28.17	24.29	0.0	0.0	0.0	0.000
66	29.60	28.68	30.24	28.85	24.98	0.0	0.0	0.0	0.000
68	29.57	28.37	30.26	28.56	24.79	0.0	0.0	0.0	0.000
70	28.64	26.63	29.68	26.93	23.28	0.0	0.0	0.0	0.000
72	28.02	25.54	29.11	25.87	22.20	0.0	0.0	0.0	0.000
74	27.92	25.06	28.93	25.38	21.79	0.0	0.0	0.0	0.000
76	27.80	24.77	28.80	25.09	21.54	0.0	0.0	0.0	0.000
78	27.61	24.57	28.64	24.90	21.30	0.0	0.0	0.0	0.000
80	27.42	24.10	28.47	24.45	20.94	0.0	0.0	0.0	0.000
82	27.21	23.86	28.30	24.22	20.68	0.0	0.0	0.0	0.000
84	27.04	23.69	28.14	24.06	20.47	0.0	0.0	0.0	0.000
86	26.93	23.56	28.03	23.93	20.31	0.0	0.0	0.0	0.000
88	26.82	23.43	27.92	23.80	20.16	0.0	0.0	0.0	0.000
90	26.70	23.31	27.81	23.68	20.00	0.0	0.0	0.0	0.000
92	26.59	23.18	27.70	23.56	19.85	0.0	0.0	0.0	0.000
94	26.48	23.05	27.60	23.43	19.70	0.0	0.0	0.0	0.000
96	26.36	22.92	27.49	23.31	19.55	0.0	0.0	0.0	0.000
98	26.28	22.86	27.41	23.25	19.45	0.0	0.0	0.0	0.000
100	26.26	22.85	27.37	23.23	19.40	0.0	0.0	0.0	0.000
102	26.26	22.82	27.35	23.20	19.38	0.0	0.0	0.0	0.000
104	26.27	22.80	27.35	23.17	19.36	0.0	0.0	0.0	0.000
106	26.27	22.77	27.33	23.14	19.34	0.0	0.0	0.0	0.000
108	26.27	22.74	27.32	23.10	19.31	0.0	0.0	0.0	0.000
110	26.27	22.72	27.31	23.08	19.29	0.0	0.0	0.0	0.000
112	26.27	22.69	27.31	23.05	19.28	0.0	0.0	0.0	0.000
114	26.28	22.65	27.31	23.01	19.26	0.0	0.0	0.0	0.000
116	26.30	22.61	27.31	22.96	19.25	0.0	0.0	0.0	0.000

118	26.31	22.55	27.32	22.90	19.23	0.0	0.0	0.0	0.000
120	26.32	22.50	27.32	22.85	19.22	0.0	0.0	0.0	0.000
122	26.55	23.01	27.47	23.33	19.54	0.0	0.0	0.0	0.000
124	27.05	23.96	27.83	24.22	20.25	0.0	0.0	0.0	0.000
126	27.87	24.50	28.42	24.69	21.01	0.0	0.0	0.0	0.000
128	28.57	28.22	29.04	28.35	23.60	0.0	0.0	0.0	0.000
130	28.93	28.66	29.42	28.79	24.24	0.0	0.0	0.0	0.000
132	29.07	28.55	29.59	28.69	24.32	0.0	0.0	0.0	0.000
134	29.01	28.91	29.61	29.07	24.60	0.0	0.0	0.0	0.000
136	29.05	28.59	29.65	28.75	24.41	0.0	0.0	0.0	0.000
138	29.04	27.78	29.66	27.96	23.89	0.0	0.0	0.0	0.000
140	28.44	26.40	29.30	26.66	22.79	0.0	0.0	0.0	0.000
142	28.56	25.97	29.25	26.18	22.49	0.0	0.0	0.0	0.000
144	29.19	28.11	29.69	28.25	24.11	0.0	0.0	0.0	0.000
146	29.62	29.41	30.08	29.53	25.34	0.0	0.0	0.0	0.000
148	29.87	29.11	30.31	29.23	25.30	0.0	0.0	0.0	0.000
150	29.95	29.45	30.42	29.57	25.65	0.0	0.0	0.0	0.000
152	29.92	29.41	30.45	29.55	25.65	0.0	0.0	0.0	0.000
154	29.89	29.43	30.44	29.57	25.66	0.0	0.0	0.0	0.000
156	30.21	30.04	30.65	30.15	26.28	0.0	0.0	0.0	0.000
158	30.33	30.18	30.80	30.30	26.52	0.0	0.0	0.0	0.000
160	30.64	30.16	31.02	30.26	26.65	0.0	0.0	0.0	0.000
162	30.60	29.89	31.07	30.01	26.49	0.0	0.0	0.0	0.000
164	30.31	29.22	30.89	29.37	25.87	0.0	0.0	0.0	0.000
166	30.05	28.50	30.69	28.68	25.21	0.0	0.0	0.0	0.000

A3.2.3 Tailgate of the Retreating Face for the Second Week

Transient temperature predictions by Jordan method

Input Data of Control Integer

Airway type	:	0
No. of sections	:	5
Type of ventilation	:	1
No. of conditioning week	:	1
Recirculation or leakage	:	0

Input Data for Airway

Average air flow velocity	:	2.49	m/s
Initial virgin strata temperature	:	38.30	C
Geothermal gradient	:	0.03	C/m
Initial depth	:	913.00	m
Final depth	:	913.00	m
Length of airway	:	416.00	m
X sectional area	:	13.50	m^2
Advance rate	:	0.38	m/hr
Initial age of the airway	:	0.40E+04	hr
Average wetness factor	:	0.00	
Thermal conductivity of rock	:	2.69	W/m C

TIME Hour	DB1 C	WB1 C	DB2 C	WB2 C	EFF2 C	QMACH KW	QCOALT KW	QSTORE KW	MOISTURE Kg/Kg

0	29.55	27.12	29.83	27.21	23.57	0.0	0.0	0.0	0.000
2	29.45	27.48	30.17	27.69	24.14	0.0	0.0	0.0	0.000
4	29.23	27.44	29.97	27.65	23.96	0.0	0.0	0.0	0.000
6	28.84	26.29	29.73	26.56	23.11	0.0	0.0	0.0	0.000
8	28.08	24.60	29.20	24.96	21.82	0.0	0.0	0.0	0.000
10	28.03	23.93	29.02	24.26	21.34	0.0	0.0	0.0	0.000
12	27.85	23.24	28.91	23.61	20.95	0.0	0.0	0.0	0.000
14	28.32	23.45	29.13	23.74	21.18	0.0	0.0	0.0	0.000
16	28.36	24.61	29.24	24.90	21.82	0.0	0.0	0.0	0.000
18	28.04	24.92	29.04	25.24	21.82	0.0	0.0	0.0	0.000
20	28.12	24.67	29.03	24.97	21.67	0.0	0.0	0.0	0.000
22	28.84	26.74	29.50	26.94	23.13	0.0	0.0	0.0	0.000
24	28.98	27.13	29.74	27.35	23.58	0.0	0.0	0.0	0.000
26	29.34	27.06	29.97	27.25	23.71	0.0	0.0	0.0	0.000
28	29.29	27.34	30.03	27.55	23.95	0.0	0.0	0.0	0.000
30	29.02	26.24	29.85	26.49	23.17	0.0	0.0	0.0	0.000
32	28.36	24.86	29.40	25.20	22.10	0.0	0.0	0.0	0.000
34	28.42	24.40	29.31	24.70	21.78	0.0	0.0	0.0	0.000
36	29.05	26.39	29.72	26.60	23.12	0.0	0.0	0.0	0.000
38	29.37	26.59	30.03	26.79	23.49	0.0	0.0	0.0	0.000
40	29.19	25.57	29.97	25.82	22.90	0.0	0.0	0.0	0.000
42	28.83	25.20	29.72	25.49	22.52	0.0	0.0	0.0	0.000
44	29.13	26.39	29.84	26.61	23.23	0.0	0.0	0.0	0.000
46	29.47	26.70	30.12	26.90	23.62	0.0	0.0	0.0	0.000
48	29.41	27.15	30.14	27.37	23.92	0.0	0.0	0.0	0.000
50	29.44	27.14	30.15	27.35	23.91	0.0	0.0	0.0	0.000
52	29.51	26.67	30.20	26.88	23.67	0.0	0.0	0.0	0.000
54	29.68	25.74	30.30	25.95	23.23	0.0	0.0	0.0	0.000
56	29.18	24.53	30.03	24.82	22.42	0.0	0.0	0.0	0.000
58	28.26	23.13	29.35	23.51	21.27	0.0	0.0	0.0	0.000
60	27.61	22.25	28.77	22.67	20.44	0.0	0.0	0.0	0.000
62	27.31	21.88	28.46	22.30	20.03	0.0	0.0	0.0	0.000
64	27.18	21.65	28.32	22.07	19.82	0.0	0.0	0.0	0.000
66	26.97	21.31	28.14	21.75	19.55	0.0	0.0	0.0	0.000
68	26.81	21.14	27.98	21.58	19.35	0.0	0.0	0.0	0.000
70	26.68	21.03	27.86	21.47	19.20	0.0	0.0	0.0	0.000
72	26.59	20.97	27.76	21.41	19.10	0.0	0.0	0.0	0.000
74	26.48	20.85	27.66	21.30	18.97	0.0	0.0	0.0	0.000
76	26.12	20.50	27.41	20.99	18.64	0.0	0.0	0.0	0.000
78	26.06	20.50	27.29	20.97	18.52	0.0	0.0	0.0	0.000
80	26.01	20.52	27.23	20.98	18.47	0.0	0.0	0.0	0.000
82	25.93	20.38	27.14	20.84	18.35	0.0	0.0	0.0	0.000
84	25.86	20.21	27.06	20.67	18.22	0.0	0.0	0.0	0.000
86	25.75	20.01	26.96	20.48	18.07	0.0	0.0	0.0	0.000
88	25.70	19.85	26.89	20.32	17.96	0.0	0.0	0.0	0.000
90	25.95	19.88	27.03	20.31	18.08	0.0	0.0	0.0	0.000
92	25.99	20.18	27.09	20.61	18.23	0.0	0.0	0.0	0.000
94	25.73	20.12	26.92	20.58	18.07	0.0	0.0	0.0	0.000
96	25.49	20.04	26.72	20.52	17.86	0.0	0.0	0.0	0.000
98	25.30	19.95	26.56	20.44	17.69	0.0	0.0	0.0	0.000
100	25.33	19.94	26.53	20.41	17.65	0.0	0.0	0.0	0.000
102	27.84	23.72	28.06	23.81	20.29	0.0	0.0	0.0	0.000
104	27.84	23.72	28.58	23.98	20.82	0.0	0.0	0.0	0.000
106	27.84	23.72	28.52	23.96	20.76	0.0	0.0	0.0	0.000
108	27.84	23.72	28.57	23.97	20.82	0.0	0.0	0.0	0.000
110	27.84	23.72	28.59	23.98	20.83	0.0	0.0	0.0	0.000
112	27.84	23.72	28.61	23.99	20.86	0.0	0.0	0.0	0.000
114	27.84	23.72	28.63	23.99	20.87	0.0	0.0	0.0	0.000
116	27.84	23.72	28.64	24.00	20.88	0.0	0.0	0.0	0.000
118	27.84	23.72	28.64	24.00	20.89	0.0	0.0	0.0	0.000
120	27.84	23.72	28.65	24.00	20.89	0.0	0.0	0.0	0.000
122	27.84	23.72	28.65	24.00	20.89	0.0	0.0	0.0	0.000
124	27.84	23.72	28.64	24.00	20.89	0.0	0.0	0.0	0.000
126	27.84	23.72	28.63	23.99	20.88	0.0	0.0	0.0	0.000
128	27.84	23.72	28.63	23.99	20.88	0.0	0.0	0.0	0.000
130	27.84	23.72	28.63	23.99	20.88	0.0	0.0	0.0	0.000
132	27.84	23.72	28.63	23.99	20.87	0.0	0.0	0.0	0.000

134	27.84	23.72	28.62	23.99	20.87	0.0	0.0	0.0	0.000
136	27.84	23.72	28.62	23.99	20.86	0.0	0.0	0.0	0.000
138	27.84	23.72	28.62	23.99	20.86	0.0	0.0	0.0	0.000
140	27.84	23.72	28.63	23.99	20.87	0.0	0.0	0.0	0.000
142	27.84	23.72	28.64	23.99	20.88	0.0	0.0	0.0	0.000
144	27.84	23.72	28.64	23.99	20.88	0.0	0.0	0.0	0.000
146	27.84	23.72	28.64	24.00	20.89	0.0	0.0	0.0	0.000
148	27.84	23.72	28.65	24.00	20.90	0.0	0.0	0.0	0.000
150	27.84	23.72	28.65	24.00	20.89	0.0	0.0	0.0	0.000
152	27.84	23.72	28.65	24.00	20.90	0.0	0.0	0.0	0.000
154	27.84	23.72	28.65	24.00	20.89	0.0	0.0	0.0	0.000
156	27.84	23.72	28.65	24.00	20.89	0.0	0.0	0.0	0.000
158	27.84	23.72	28.66	24.00	20.91	0.0	0.0	0.0	0.000
160	27.84	23.72	28.67	24.01	20.92	0.0	0.0	0.0	0.000
162	27.84	23.72	28.68	24.01	20.92	0.0	0.0	0.0	0.000
164	27.84	23.72	28.69	24.01	20.93	0.0	0.0	0.0	0.000
166	27.84	23.72	28.69	24.01	20.94	0.0	0.0	0.0	0.000

APPENDIX IV

DESCRIPTIONS OF GLOBAL VARIABLES

Global Variables are used in the main programme (Appendix I). Some of these global variables have two dimensional arrays. The first dimension represents the data at each time interval and the second dimension represents the data at each section of the roadway. If the variable has only one dimension array, each element in the array represents the data at that time interval.

Since the input variables in the main programme have already been described in Appendix II, the descriptions of the global variables, except the input variables, are as follows:

DRY1(0:460)	=	dry bulb temperature, at time t, at the start of the section of the roadway (°C)
DRY2(0:460)	=	dry bulb temperature, at time t, at the end of the section of the roadway (°C)
ETA(0:460)	=	wetness factor at time t
FI(0:460)	=	temperature function of the strata at time t
FIMEAN(460)	=	mean temperature function of the strata at time t
PMACH(0:83,10)	=	the power rating of machinery (W)
QCOALT(0:83,10)	=	total heat flux from the conveyed coal (W)
QCOALW(0:83,10)	=	wet heat flux from the conveyed coal (W)
QP(0:83)	=	a dummy variable at time t
QST1(0:83)	=	total heat flux from strata, at time t, at the start of the section of the roadway (W)
QST2(0:83)	=	total heat flux from strata, at time t, at the start of the section of the roadway (W)
QSTLT(0:83,10)	=	total heat flux from the steel (W)

QSTLW(0:83,10)	=	wet heat flux from the steel (W)
QSW1(0:83)	=	wet heat flux from strata, at time t, at the start of the section of the roadway (W)
QSW2(0:83)	=	wet heat flux from strata, at time t, at the end of the section of the roadway (W)
RAYAGE(0:10)	=	the ventilated age at each section of the roadway (hr)
RAYVST(0:10)	=	the virgin srtrata temperature at each section of the roadway (°C)
T1(0:460)	=	surface temperature, at time t, at the start of the section of the roadway (°C)
T2(0:460)	=	surface temperature, at time t, at the end of the section of the roadway (°C)
TEMDRY(0:83)	=	dummy variable for the dry bulb temperatures at time t (°C)
TEMDWET(0:83)	=	dummy variable for the wet bulb temperatures at time t (°C)
VAPOUR(0:83,10)	=	moisture contents of the air gained in the roadway (kg/kg)
VDSAVE(0:83)	=	dummy variable for air velocity (m/s)
WET1(0:460)	=	wet bulb temperature, at time t, at the start of the section of the roadway (°C)
WET2(0:460)	=	wet bulb temperature, at time t, at the end of the section of the roadway (°C)

APPENDIX V

TEMPERATURE DATA

A5.1 WEARMOUTH COLLIERY

A5.1.1 Main drift

The following are the temperature readings processed by Maneylaws (1988) of HQTD from the temperature survey undertaken at the main drift on Level 1850 of Wearmouth Colliery.

		Temperatures (°C)			
		Station 1.		Station 2.	
Date	Time	Dry bulb	Wet bulb	Dry bulb	Wet bulb
17/5	11.000	25.755	21.718	25.735	22.029
17/5	12.000	25.757	21.771	25.769	22.089
17/5	13.000	25.773	21.800	25.813	22.167
17/5	14.000	25.875	21.941	25.850	22.206
17/5	15.000	25.987	22.080	25.854	22.152
17/5	16.000	25.995	22.054	25.850	22.032
17/5	17.000	25.983	21.941	25.842	22.167
17/5	18.000	25.981	22.119	25.833	22.118
17/5	19.000	25.978	22.161	25.824	22.157
17/5	20.000	25.976	22.162	25.814	22.181
17/5	21.000	25.973	22.163	25.804	22.130
17/5	22.000	25.971	22.163	25.793	21.982
17/5	23.000	25.968	22.164	25.783	21.981
18/5	0.0	25.966	22.165	25.772	22.050
18/5	1.000	25.963	22.165	25.764	21.973
18/5	2.000	25.961	22.166	25.772	22.023
18/5	3.000	25.958	22.167	25.738	21.997
18/5	4.000	25.956	22.167	25.665	21.822
18/5	5.000	25.953	22.168	25.554	21.666
18/5	6.000	25.951	22.168	25.527	21.688
18/5	7.000	25.949	22.169	25.569	21.863
18/5	8.000	25.946	22.170	25.616	21.927
18/5	9.000	25.943	22.170	25.661	21.989
18/5	10.000	25.941	22.171	25.673	21.927
18/5	11.000	25.939	22.171	25.660	22.004
18/5	12.000	25.936	22.172	25.663	22.136
18/5	13.000	25.934	22.173	25.704	22.107
18/5	14.000	25.931	22.173	25.747	22.100
18/5	15.000	25.929	22.174	25.784	22.160
18/5	16.000	25.926	22.175	25.794	22.099
18/5	17.000	25.924	22.175	25.800	22.179
18/5	18.000	25.921	22.176	25.812	22.188
18/5	19.000	25.919	22.176	25.827	22.260
18/5	20.000	25.916	22.177	25.797	22.173
18/5	21.000	25.914	22.178	25.699	22.106

18/5	22.000	25.911	22.178	25.678	21.996
18/5	23.000	25.909	22.179	25.692	21.974
19/5	0.0	25.906	22.180	25.701	22.022
19/5	1.000	25.904	22.180	25.705	22.022
19/5	2.000	25.901	22.181	25.709	22.018
19/5	3.000	25.899	22.182	25.710	22.003
19/5	4.000	25.896	22.182	25.711	21.936
19/5	5.000	25.894	22.183	25.712	21.843
19/5	6.000	25.891	22.183	25.717	21.939
19/5	7.000	25.889	22.184	25.726	21.950
19/5	8.000	25.887	22.185	25.734	22.037
19/5	9.000	25.884	22.185	25.656	21.980
19/5	10.000	25.882	22.186	25.561	21.786
19/5	11.000	25.882	22.177	25.603	21.847
19/5	12.000	25.891	22.265	25.667	21.920
19/5	13.000	25.903	22.293	25.727	22.005
19/5	14.000	25.914	22.366	25.758	22.061
19/5	15.000	25.926	22.357	25.785	22.006
19/5	16.000	25.934	22.280	25.812	21.940
19/5	17.000	25.929	22.167	25.836	21.948
19/5	18.000	25.923	22.210	25.826	21.980
19/5	19.000	25.916	22.246	25.801	22.047
19/5	20.000	25.910	22.321	25.781	21.995
19/5	21.000	25.905	22.330	25.770	22.005
19/5	22.000	25.902	22.305	25.758	21.891
19/5	23.000	25.898	22.091	25.747	21.775
20/5	0.0	25.895	22.120	25.735	21.781
20/5	1.000	25.891	22.158	25.723	21.829
20/5	2.000	25.888	22.208	25.712	21.848
20/5	3.000	25.886	22.136	25.706	21.786
20/5	4.000	25.888	22.139	25.713	21.740
20/5	5.000	25.889	21.997	25.723	21.768
20/5	6.000	25.890	22.289	25.734	21.896
20/5	7.000	25.892	22.265	25.744	21.846
20/5	8.000	25.893	22.336	25.753	21.884
20/5	9.000	25.868	22.255	25.758	21.892
20/5	10.000	25.794	22.131	25.763	21.820
20/5	11.000	25.719	21.971	25.768	21.796
20/5	12.000	25.666	22.137	25.773	21.904
20/5	13.000	25.642	22.087	25.778	21.856
20/5	14.000	25.620	22.009	25.782	21.866
20/5	15.000	25.598	22.057	25.787	21.919
20/5	16.000	25.577	22.038	25.792	21.849
20/5	17.000	25.555	21.857	25.799	21.825
20/5	18.000	25.543	22.077	25.819	21.917
20/5	19.000	25.640	22.198	25.841	21.961
20/5	20.000	25.786	22.342	25.864	22.001
20/5	21.000	25.783	22.322	25.886	21.964
20/5	22.000	25.747	22.232	25.887	21.897
20/5	23.000	25.652	21.983	25.831	21.748
21/5	0.0	25.543	21.813	25.776	21.674
21/5	1.000	25.433	21.653	25.723	21.606
21/5	2.000	25.323	21.493	25.670	21.537
21/5	3.000	25.212	21.333	25.617	21.469
21/5	4.000	25.132	21.225	25.564	21.400
21/5	5.000	25.088	21.179	25.511	21.332
21/5	6.000	25.044	21.133	25.458	21.263
21/5	7.000	25.001	21.088	25.405	21.195
21/5	8.000	24.967	21.044	25.361	21.135
21/5	9.000	24.935	21.001	25.349	21.104
21/5	10.000	24.906	20.962	25.340	21.076
21/5	11.000	24.883	20.934	25.331	21.049
21/5	12.000	24.861	20.907	25.321	21.021
21/5	13.000	24.839	20.880	25.312	20.993

21/5	14.000	24.818	20.854	25.300	20.972
21/5	15.000	24.796	20.827	25.286	20.958
21/5	16.000	24.774	20.800	25.272	20.943
21/5	17.000	24.755	20.775	25.258	20.929
21/5	18.000	24.744	20.752	25.244	20.914
21/5	19.000	24.733	20.729	25.230	20.900
21/5	20.000	24.722	20.706	25.216	20.886
21/5	21.000	24.710	20.683	25.200	20.867
21/5	22.000	24.693	20.662	25.178	20.839
21/5	23.000	24.673	20.642	25.156	20.812
22/5	0.0	24.653	20.621	25.134	20.784
22/5	1.000	24.633	20.601	25.113	20.757
22/5	2.000	24.614	20.580	25.091	20.729
22/5	3.000	24.595	20.561	25.073	20.707
22/5	4.000	24.588	20.549	25.071	20.703
22/5	5.000	24.584	20.539	25.070	20.701
22/5	6.000	24.580	20.530	25.068	20.699
22/5	7.000	24.570	20.529	25.067	20.697
22/5	8.000	24.555	20.517	25.066	20.695
22/5	9.000	24.540	20.509	25.064	20.693
22/5	10.000	24.525	20.488	25.063	20.691
22/5	11.000	24.510	20.467	25.062	20.689
22/5	12.000	24.494	20.446	25.055	20.678
22/5	13.000	24.486	20.430	25.043	20.661
22/5	14.000	24.489	20.423	25.032	20.645
22/5	15.000	24.492	20.415	25.020	20.628
22/5	16.000	24.495	20.408	25.009	20.611
22/5	17.000	24.497	20.400	25.006	20.595
22/5	18.000	24.504	20.397	25.006	20.579
22/5	19.000	24.538	20.433	25.007	20.563
22/5	20.000	24.579	20.478	25.008	20.547
22/5	21.000	24.620	20.523	25.015	20.539
22/5	22.000	24.660	20.567	25.099	20.617
22/5	23.000	24.710	20.619	25.206	20.722
23/5	0.0	24.816	20.831	25.314	20.947
23/5	1.000	24.885	21.196	25.378	21.158
23/5	2.000	24.928	21.324	25.429	21.242
23/5	3.000	24.929	21.399	25.480	21.241
23/5	4.000	25.052	21.566	25.527	21.355
23/5	5.000	25.161	21.524	25.538	21.306
23/5	6.000	25.177	21.629	25.539	21.276
23/5	7.000	25.192	21.734	25.540	21.322
23/5	8.000	25.201	21.768	25.575	21.384
23/5	9.000	25.207	21.824	25.636	21.477
23/5	10.000	25.214	21.746	25.692	21.486
23/5	11.000	25.245	21.626	25.718	21.387
23/5	12.000	25.313	21.781	25.721	21.438
23/5	13.000	25.368	21.906	25.743	21.534
23/5	14.000	25.374	21.986	25.745	21.596
23/5	15.000	25.373	21.936	25.736	21.582
23/5	16.000	25.375	22.016	25.728	21.585
23/5	17.000	25.385	21.861	25.710	21.423
23/5	18.000	25.394	21.905	25.686	21.394
23/5	19.000	25.404	21.936	25.661	21.446
23/5	20.000	25.414	21.961	25.641	21.357
23/5	21.000	25.419	21.937	25.637	21.336
23/5	22.000	25.423	21.847	25.639	21.311
23/5	23.000	25.428	21.825	25.641	21.284
24/5	0.0	25.432	21.963	25.643	21.306
24/5	1.000	25.428	22.097	25.647	21.453
24/5	2.000	25.408	22.027	25.667	21.400
24/5	3.000	25.380	21.995	25.694	21.467
24/5	4.000	25.350	21.893	25.726	21.459
24/5	5.000	25.339	21.792	25.758	21.436
24/5	6.000	25.380	21.980	25.790	21.481
24/5	7.000	25.443	22.098	25.822	21.601
24/5	8.000	25.508	22.119	25.854	21.655

A5.1.2 Conveyor Roadway

The following are the temperature readings processed by Maneylaws (1988) of HQTD from the temperature survey undertaken at the conveyor roadway on Level 1850 of Wearmouth Colliery.

		Temperatures (°C)			
		Station 1.		Station 3.	
Date	Time	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb
17/ 5	11.000	25.755	21.718	24.958	21.583
17/ 5	12.000	25.757	21.771	24.930	21.508
17/ 5	13.000	25.773	21.800	24.903	21.457
17/ 5	14.000	25.875	21.941	24.876	21.428
17/ 5	15.000	25.987	22.080	24.850	21.402
17/ 5	16.000	25.995	22.054	24.823	21.378
17/ 5	17.000	25.983	21.941	24.798	21.356
17/ 5	18.000	25.981	22.119	24.777	21.326
17/ 5	19.000	25.978	22.161	24.768	21.272
17/ 5	20.000	25.976	22.162	24.759	21.218
17/ 5	21.000	25.973	22.163	24.750	21.197
17/ 5	22.000	25.971	22.163	24.741	21.198
17/ 5	23.000	25.968	22.164	24.733	21.193
18/ 5	0.0	25.966	22.165	24.724	21.164
18/ 5	1.000	25.963	22.165	24.715	21.111
18/ 5	2.000	25.961	22.166	24.706	21.035
18/ 5	3.000	25.958	22.167	24.698	20.955
18/ 5	4.000	25.956	22.167	24.706	20.922
18/ 5	5.000	25.953	22.168	24.742	21.025
18/ 5	6.000	25.951	22.168	24.786	20.997
18/ 5	7.000	25.949	22.169	24.830	21.029
18/ 5	8.000	25.946	22.170	24.874	21.022
18/ 5	9.000	25.943	22.170	24.903	20.993
18/ 5	10.000	25.941	22.171	24.908	20.967
18/ 5	11.000	25.939	22.171	24.912	20.940
18/ 5	12.000	25.936	22.172	24.916	20.914
18/ 5	13.000	25.934	22.173	24.920	20.887
18/ 5	14.000	25.931	22.173	24.924	20.861
18/ 5	15.000	25.929	22.174	24.928	20.835
18/ 5	16.000	25.926	22.175	24.932	20.808
18/ 5	17.000	25.924	22.175	24.936	20.782
18/ 5	18.000	25.921	22.176	24.941	20.755
18/ 5	19.000	25.919	22.176	24.945	20.729
18/ 5	20.000	25.916	22.177	24.949	20.702
18/ 5	21.000	25.914	22.178	24.953	20.676
18/ 5	22.000	25.911	22.178	24.957	20.650
18/ 5	23.000	25.909	22.179	24.961	20.623
19/ 5	0.0	25.906	22.180	24.965	20.597
19/ 5	1.000	25.904	22.180	24.969	20.570
19/ 5	2.000	25.901	22.181	24.973	20.544
19/ 5	3.000	25.899	22.182	24.978	20.518

19/5	4.000	25.896	22.182	24.982	20.491
19/5	5.000	25.894	22.183	24.986	20.465
19/5	6.000	25.891	22.183	24.990	20.445
19/5	7.000	25.889	22.184	24.994	20.439
19/5	8.000	25.887	22.185	24.997	20.491
19/5	9.000	25.884	22.185	24.999	20.457
19/5	10.000	25.882	22.186	25.000	20.532
19/5	11.000	25.882	22.177	25.012	20.405
19/5	12.000	25.891	22.265	25.040	20.490
19/5	13.000	25.903	22.293	25.051	20.479
19/5	14.000	25.914	22.366	25.039	20.444
19/5	15.000	25.926	22.357	25.023	20.418
19/5	16.000	25.934	22.280	25.007	20.415
19/5	17.000	25.929	22.167	24.991	20.424
19/5	18.000	25.923	22.210	24.981	20.381
19/5	19.000	25.916	22.246	24.974	20.462
19/5	20.000	25.910	22.321	24.968	20.372
19/5	21.000	25.905	22.330	24.961	20.359
19/5	22.000	25.902	22.305	24.955	20.335
19/5	23.000	25.898	22.091	24.952	20.315
20/5	0.0	25.895	22.120	24.956	20.311
20/5	1.000	25.891	22.158	24.964	20.373
20/5	2.000	25.888	22.208	24.975	20.390
20/5	3.000	25.886	22.136	24.985	20.430
20/5	4.000	25.888	22.139	24.995	20.397
20/5	5.000	25.889	21.997	25.004	20.400
20/5	6.000	25.890	22.289	25.005	20.373
20/5	7.000	25.892	22.265	25.002	20.404
20/5	8.000	25.893	22.336	24.996	20.422
20/5	9.000	25.868	22.255	24.989	20.452
20/5	10.000	25.794	22.131	24.983	20.392
20/5	11.000	25.719	21.971	24.976	20.425
20/5	12.000	25.666	22.137	24.969	20.366
20/5	13.000	25.642	22.087	24.963	20.403
20/5	14.000	25.620	22.009	24.956	20.354
20/5	15.000	25.598	22.057	24.950	20.397
20/5	16.000	25.577	22.038	24.943	20.321
20/5	17.000	25.555	21.857	24.936	20.331
20/5	18.000	25.543	22.077	24.930	20.329
20/5	19.000	25.640	22.198	24.923	20.374
20/5	20.000	25.786	22.342	24.917	20.377
20/5	21.000	25.783	22.322	24.910	20.298
20/5	22.000	25.747	22.232	24.903	20.277
20/5	23.000	25.652	21.983	24.896	20.262
21/5	0.0	25.543	21.813	24.890	20.325
21/5	1.000	25.433	21.653	24.883	20.271
21/5	2.000	25.323	21.493	24.875	20.232
21/5	3.000	25.212	21.333	24.858	20.254
21/5	4.000	25.132	21.225	24.835	20.218
21/5	5.000	25.088	21.179	24.812	20.174
21/5	6.000	25.044	21.133	24.788	20.129
21/5	7.000	25.001	21.088	24.765	20.083
21/5	8.000	24.967	21.044	24.743	20.208
21/5	9.000	24.935	21.001	24.726	20.143
21/5	10.000	24.906	20.962	24.711	20.090
21/5	11.000	24.883	20.934	24.699	20.049
21/5	12.000	24.861	20.907	24.695	20.039
21/5	13.000	24.839	20.880	24.693	20.031
21/5	14.000	24.818	20.854	24.690	20.023
21/5	15.000	24.796	20.827	24.687	20.016
21/5	16.000	24.774	20.800	24.684	20.008
21/5	17.000	24.755	20.775	24.681	20.000
21/5	18.000	24.744	20.752	24.678	19.993
21/5	19.000	24.733	20.729	24.675	19.985
21/5	20.000	24.722	20.706	24.672	19.977
21/5	21.000	24.710	20.683	24.669	19.969

21/5	22.000	24.693	20.662	24.667	19.962
21/5	23.000	24.673	20.642	24.664	19.954
22/5	0.0	24.653	20.621	24.660	19.954
22/5	1.000	24.633	20.601	24.654	19.962
22/5	2.000	24.614	20.580	24.649	19.969
22/5	3.000	24.595	20.561	24.644	19.976
22/5	4.000	24.588	20.549	24.639	19.999
22/5	5.000	24.584	20.539	24.634	19.938
22/5	6.000	24.580	20.530	24.629	19.929
22/5	7.000	24.570	20.529	24.624	19.920
22/5	8.000	24.555	20.517	24.618	19.978
22/5	9.000	24.540	20.509	24.614	19.948
22/5	10.000	24.525	20.488	24.610	19.951
22/5	11.000	24.510	20.467	24.606	19.954
22/5	12.000	24.494	20.446	24.602	19.957
22/5	13.000	24.486	20.430	24.598	19.960
22/5	14.000	24.489	20.423	24.594	19.963
22/5	15.000	24.492	20.415	24.590	19.966
22/5	16.000	24.495	20.408	24.586	19.969
22/5	17.000	24.497	20.400	24.582	19.972
22/5	18.000	24.504	20.397	24.578	19.975
22/5	19.000	24.538	20.433	24.575	19.978
22/5	20.000	24.579	20.478	24.573	19.978
22/5	21.000	24.620	20.523	24.572	19.978
22/5	22.000	24.660	20.567	24.572	19.974
22/5	23.000	24.710	20.619	24.573	19.966
23/5	0.0	24.816	20.831	24.582	19.962
23/5	1.000	24.885	21.196	24.603	19.961
23/5	2.000	24.928	21.324	24.624	19.960
23/5	3.000	24.929	21.399	24.645	20.065
23/5	4.000	25.052	21.566	24.664	20.114
23/5	5.000	25.161	21.524	24.675	20.198
23/5	6.000	25.177	21.629	24.664	20.125
23/5	7.000	25.192	21.734	24.648	20.139
23/5	8.000	25.201	21.768	24.635	20.114
23/5	9.000	25.207	21.824	24.645	20.129
23/5	10.000	25.214	21.746	24.706	20.191
23/5	11.000	25.245	21.626	24.763	20.242
23/5	12.000	25.313	21.781	24.782	20.228
23/5	13.000	25.368	21.906	24.792	20.186
23/5	14.000	25.374	21.986	24.792	20.331
23/5	15.000	25.373	21.936	24.759	20.224
23/5	16.000	25.375	22.016	24.724	20.295
23/5	17.000	25.385	21.861	24.701	20.160
23/5	18.000	25.394	21.905	24.700	20.148
23/5	19.000	25.404	21.936	24.705	20.153
23/5	20.000	25.414	21.961	24.711	20.159
23/5	21.000	25.419	21.937	24.717	20.165
23/5	22.000	25.423	21.847	24.734	20.172
23/5	23.000	25.428	21.825	24.756	20.244
24/5	0.0	25.432	21.963	24.779	20.252
24/5	1.000	25.428	22.097	24.800	20.290
24/5	2.000	25.408	22.027	24.822	20.317
24/5	3.000	25.380	21.995	24.844	20.323
24/5	4.000	25.350	21.893	24.867	20.316
24/5	5.000	25.339	21.792	24.898	20.378
24/5	6.000	25.380	21.980	24.934	20.430
24/5	7.000	25.443	22.098	24.970	20.641

A5.1.3 An Advancing Face Working District for the First Week

The following are the temperature readings processed by Maneylaws (1988) of HQTD from the temperature survey undertaken at the advancing face working district on Level 1850 of Wearmouth Colliery.

Four thermohygrograph stations were positioned around the working district. Two stations were in the maingate; station 1. at the outbye end and station 2. at the inbye end. Two stations were in the tailgate; 3. at the inbye end and 4. at the outbye end.

Temperatures (°C)

		Station 1.		Station 2.		Station 3.		Station 4.	
Date	Time	D B	W B	D B	W B	D B	W B	D B	W B
15/6	11.00	27.83	22.77	27.54	25.28	28.55	27.48	27.80	26.71
15/6	12.00	27.93	22.97	27.65	25.50	28.60	27.14	27.81	26.72
15/6	13.00	27.95	22.95	27.69	25.49	28.37	27.52	27.81	26.73
15/6	14.00	27.91	23.14	27.82	25.71	28.43	27.65	27.81	26.75
15/6	15.00	27.87	23.16	27.94	25.81	28.46	27.74	27.82	26.76
15/6	16.00	27.78	23.03	28.02	25.86	28.65	27.89	27.82	26.77
15/6	17.00	27.62	22.77	27.55	25.25	28.62	27.86	27.82	26.78
15/6	18.00	27.48	22.62	27.23	24.87	28.52	27.78	27.83	26.79
15/6	19.00	27.55	22.65	27.03	24.73	28.39	27.58	27.83	26.80
15/6	20.00	27.62	22.70	26.91	24.64	28.10	27.30	27.83	26.81
15/6	21.00	27.69	22.84	27.09	24.92	28.14	27.36	27.83	26.82
15/6	22.00	27.73	22.91	27.17	24.96	28.38	27.58	27.84	26.83
15/6	23.00	27.74	22.79	27.17	24.93	28.87	27.71	27.84	26.84
16/6	0.0	27.80	22.87	27.30	25.19	29.37	27.68	27.84	26.85
16/6	1.00	27.78	22.82	27.26	25.04	29.71	27.56	27.85	26.86
16/6	2.00	27.74	22.84	27.10	24.83	29.57	27.06	27.85	26.87
16/6	3.00	27.74	22.80	27.10	24.56	28.60	26.01	27.85	26.88
16/6	4.00	27.82	22.86	27.19	24.82	28.34	25.71	27.86	26.89
16/6	5.00	27.88	22.93	27.34	25.10	28.54	27.36	27.86	26.90
16/6	6.00	27.91	22.97	27.86	25.18	28.94	27.27	27.86	26.91
16/6	7.00	27.90	23.06	27.87	24.75	29.31	27.16	27.87	26.92
16/6	8.00	27.90	23.07	27.89	25.46	28.82	26.41	27.87	26.92
16/6	9.00	28.00	23.17	27.89	25.43	28.50	25.92	27.87	26.92
16/6	10.00	28.34	23.40	27.62	25.12	28.40	26.48	27.87	26.92
16/6	11.00	28.78	23.66	27.58	25.50	28.21	27.06	27.87	26.92
16/6	12.00	28.84	23.61	27.59	25.52	27.94	26.91	27.87	26.92
16/6	13.00	29.27	23.91	27.65	25.66	28.22	27.41	27.87	26.92
16/6	14.00	29.57	24.15	27.68	25.65	28.30	27.49	27.87	26.92
16/6	15.00	29.43	24.06	27.71	25.66	28.28	27.45	27.87	26.92
16/6	16.00	28.98	23.73	27.68	25.63	28.38	27.57	27.87	26.92
16/6	17.00	29.25	23.79	27.58	25.54	28.42	27.62	27.88	26.92
16/6	18.00	29.62	24.00	27.58	25.57	28.31	27.43	27.88	26.92
16/6	19.00	29.75	24.04	27.65	25.67	28.31	27.37	27.88	26.92
16/6	20.00	29.89	24.14	27.70	25.76	28.40	27.48	27.88	26.92
16/6	21.00	30.09	24.25	27.82	25.85	28.45	27.55	27.88	26.92
16/6	22.00	30.19	24.36	27.82	25.82	28.59	27.69	27.88	26.93

16/6	23.00	30.32	24.40	27.59	25.47	29.00	27.77	27.88	26.94
17/6	0.0	30.43	24.32	27.10	24.51	29.19	27.46	27.88	26.95
17/6	1.00	30.56	24.38	27.21	24.27	28.58	26.42	27.88	26.95
17/6	2.00	30.58	24.30	27.56	25.24	28.09	25.64	27.88	26.94
17/6	3.00	30.59	24.32	27.81	25.76	28.10	26.59	27.88	26.94
17/6	4.00	30.56	24.36	27.74	25.71	28.18	27.25	27.88	26.94
17/6	5.00	30.55	24.30	27.56	25.50	28.65	27.44	27.88	26.94
17/6	6.00	30.80	24.43	27.40	25.39	29.11	27.41	27.88	26.94
17/6	7.00	30.86	24.45	27.45	25.49	29.43	27.25	27.88	26.93
17/6	8.00	30.59	24.58	27.52	25.57	29.69	27.13	27.88	26.93
17/6	9.00	29.08	23.65	27.57	25.63	29.34	26.49	27.88	26.93
17/6	10.00	28.93	23.60	27.39	25.08	27.95	25.00	27.88	26.93
17/6	11.00	29.11	23.53	26.88	24.14	27.76	24.91	27.88	26.93
17/6	12.00	29.85	23.90	26.81	23.77	27.97	27.00	27.88	26.93
17/6	13.00	30.28	24.11	27.15	24.76	28.05	26.87	27.88	26.92
17/6	14.00	30.55	24.48	27.49	25.47	27.72	26.08	27.88	26.92
17/6	15.00	30.59	24.53	27.69	25.65	27.70	26.75	27.88	26.91
17/6	16.00	30.56	24.60	27.52	25.50	27.76	26.84	27.88	26.90
17/6	17.00	30.45	24.37	27.51	25.51	27.74	26.77	27.88	26.90
17/6	18.00	30.75	24.45	27.55	25.62	27.67	26.65	27.88	26.89
17/6	19.00	30.91	24.70	27.63	25.73	27.68	26.68	27.87	26.89
17/6	20.00	30.94	24.66	27.79	25.87	27.72	26.78	27.87	26.88
17/6	21.00	31.18	24.97	27.86	25.92	27.77	26.82	27.87	26.88
17/6	22.00	31.21	24.93	27.87	25.91	28.06	27.00	27.87	26.87
17/6	23.00	31.24	24.89	27.70	25.67	28.55	27.02	27.87	26.86
18/6	0.0	31.23	24.75	26.95	24.61	28.84	26.88	27.87	26.86
18/6	1.00	31.29	24.71	27.36	24.49	28.86	26.53	27.87	26.85
18/6	2.00	31.21	24.65	28.04	24.98	29.03	26.45	27.87	26.85
18/6	3.00	31.04	24.47	28.31	24.85	28.14	25.52	27.87	26.84
18/6	4.00	31.08	24.47	28.28	24.48	28.48	26.74	27.87	26.84
18/6	5.00	31.04	24.40	28.28	24.29	28.73	26.78	27.87	26.83
18/6	6.00	31.08	24.36	28.37	24.27	28.82	26.49	27.87	26.83
18/6	7.00	31.13	24.41	28.38	24.15	28.83	26.27	27.88	26.83
18/6	8.00	31.13	24.35	28.41	24.10	28.40	25.70	27.89	26.83
18/6	9.00	31.36	24.55	28.44	24.11	27.97	25.82	27.89	26.83
18/6	10.00	31.26	24.51	28.48	24.11	28.23	26.92	27.90	26.83
18/6	11.00	30.95	24.32	28.56	24.09	28.49	26.67	27.91	26.83
18/6	12.00	31.04	24.27	28.56	24.01	28.60	26.37	27.91	26.83
18/6	13.00	31.09	24.23	28.53	23.92	28.61	26.10	27.92	26.83
18/6	14.00	31.14	24.22	28.50	23.84	28.60	25.89	27.93	26.83
18/6	15.00	31.16	24.21	28.47	23.75	28.61	25.80	27.93	26.83
18/6	16.00	31.16	24.20	28.44	23.68	28.62	25.78	27.94	26.83
18/6	17.00	31.15	24.19	28.41	23.64	28.62	25.75	27.95	26.83
18/6	18.00	31.16	24.18	28.38	23.61	28.63	25.72	27.96	26.83
18/6	19.00	31.17	24.17	28.35	23.55	28.64	25.70	27.96	26.83
18/6	20.00	31.18	24.16	28.32	23.49	28.65	25.67	27.97	26.83
18/6	21.00	31.19	24.15	28.29	23.43	28.66	25.65	27.98	26.83
18/6	22.00	31.18	24.13	28.26	23.37	28.67	25.62	27.98	26.83
18/6	23.00	31.16	24.11	28.23	23.31	28.68	25.59	27.99	26.83
19/6	0.0	31.13	24.08	28.20	23.25	28.64	25.54	27.97	26.82
19/6	1.00	31.10	24.06	28.17	23.19	28.58	25.48	27.94	26.80
19/6	2.00	31.07	24.03	28.18	23.18	28.53	25.42	27.92	26.77
19/6	3.00	31.04	24.00	28.23	23.24	28.47	25.36	27.89	26.75
19/6	4.00	31.02	23.96	28.31	23.25	28.41	25.29	27.86	26.73
19/6	5.00	30.99	23.93	28.37	23.24	28.36	25.23	27.83	26.71
19/6	6.00	30.96	23.91	28.34	23.20	28.30	25.17	27.81	26.69
19/6	7.00	30.93	23.91	27.72	22.62	28.25	25.11	27.78	26.67
19/6	8.00	30.90	23.91	26.99	21.95	28.19	25.05	27.75	26.64
19/6	9.00	30.87	23.92	27.25	22.14	28.22	26.22	27.72	26.62
19/6	10.00	30.86	23.95	27.48	23.01	28.40	26.10	27.70	26.60
19/6	11.00	30.85	23.98	27.68	23.77	28.50	26.04	27.67	26.58
19/6	12.00	30.86	24.02	27.84	23.59	28.51	25.84	27.64	26.56
19/6	13.00	30.91	24.03	27.89	23.42	28.52	25.49	27.61	26.53
19/6	14.00	30.96	24.01	27.92	23.27	28.53	25.39	27.59	26.51
19/6	15.00	30.99	24.01	27.92	23.16	28.54	25.34	27.56	26.49
19/6	16.00	31.02	24.02	27.92	23.06	28.55	25.30	27.54	26.47

19/6	17.00	31.05	24.01	27.92	23.00	28.56	25.25	27.54	26.47
19/6	18.00	31.07	23.95	27.90	22.96	28.58	25.21	27.54	26.47
19/6	19.00	31.09	23.89	27.90	22.92	28.62	25.24	27.54	26.47
19/6	20.00	31.10	23.91	27.90	22.84	28.68	25.28	27.54	26.46
19/6	21.00	31.09	23.95	27.86	22.71	28.73	25.33	27.54	26.46
19/6	22.00	31.07	23.95	27.73	22.57	28.78	25.37	27.54	26.46
19/6	23.00	31.06	23.96	27.59	22.43	28.78	25.36	27.54	26.45
20/6	0.0	31.06	23.97	27.58	22.40	28.52	25.07	27.54	26.45
20/6	1.00	31.03	24.35	27.98	22.74	28.23	24.74	27.54	26.45
20/6	2.00	30.83	24.67	28.40	23.11	27.94	24.67	27.54	26.45
20/6	3.00	30.93	24.77	28.25	24.12	27.94	26.60	27.54	26.44
20/6	4.00	31.04	24.87	27.84	23.59	28.02	26.68	27.54	26.44
20/6	5.00	31.11	24.96	27.59	24.12	27.87	26.53	27.54	26.44
20/6	6.00	31.17	24.97	27.68	24.90	27.84	26.43	27.54	26.44
20/6	7.00	31.24	25.07	27.93	25.25	27.52	26.15	27.54	26.43
20/6	8.00	31.38	25.29	28.18	25.69	27.42	26.03	27.55	26.43
20/6	9.00	31.31	25.21	28.22	25.79	27.63	26.37	27.55	26.43
20/6	10.00	31.44	25.40	28.12	25.69	27.30	26.07	27.55	26.43
20/6	11.00	31.53	25.48	28.24	25.62	27.53	26.21	27.55	26.42
20/6	12.00	31.48	25.35	28.15	25.43	27.65	26.32	27.55	26.42
20/6	13.00	31.60	25.56	28.07	25.67	27.77	26.41	27.55	26.42
20/6	14.00	31.78	25.77	28.08	25.68	27.91	26:56	27.55	26.42
20/6	15.00	31.71	25.84	28.09	25.71	27.81	26.46	27.56	26.42
20/6	16.00	31.57	25.70	27.99	25.68	27.75	26.38	27.56	26.42
20/6	17.00	31.66	25.68	27.99	25.65	28.14	26.50	27.57	26.43
20/6	18.00	31.77	25.73	28.01	25.63	28.53	26.48	27.57	26.43
20/6	19.00	31.80	25.71	27.91	25.59	28.81	26.20	27.58	26.43
20/6	20.00	31.74	25.70	27.58	25.23	29.03	25.95	27.59	26.44
20/6	21.00	31.91	25.77	27.81	25.09	29.19	25.92	27.59	26.44
20/6	22.00	31.85	25.77	28.00	24.74	29.30	25.79	27.60	26.44
20/6	23.00	32.09	26.23	27.76	25.23	29.30	25.65	27.61	26.45
21/6	0.0	32.05	26.17	27.40	24.61	28.45	24.82	27.61	26.45
21/6	1.00	31.13	25.25	27.65	24.91	28.00	24.36	27.62	26.46
21/6	2.00	31.10	25.01	27.51	24.97	27.97	24.30	27.63	26.46
21/6	3.00	31.53	25.28	27.56	25.13	28.25	26.50	27.64	26.48
21/6	4.00	31.77	25.47	27.73	25.37	28.80	26.55	27.66	26.50
21/6	5.00	32.01	25.94	27.88	25.47	29.07	26.35	27.67	26.52
21/6	6.00	32.09	25.99	28.03	25.57	29.22	26.27	27.69	26.54
21/6	7.00	31.88	25.99	28.14	25.63	28.59	25.56	27.70	26.56
21/6	8.00	31.73	25.77	28.24	25.67	28.04	25.04	27.72	26.58
21/6	9.00	31.76	25.83	28.28	25.84	27.76	26.26	27.74	26.60
21/6	10.00	31.73	25.89	28.45	25.99	27.79	26.30	27.75	26.62
21/6	11.00	31.81	25.97	28.45	25.82	27.81	26.32	27.77	26.64
21/6	12.00	31.93	25.92	28.52	25.44	27.86	26.39	27.78	26.66
21/6	13.00	31.92	26.04	28.61	25.58	28.01	26.57	27.80	26.68
21/6	14.00	32.09	26.26	28.75	25.75	28.14	26.69	27.80	26.67
21/6	15.00	32.11	26.39	28.83	25.84	28.24	26.75	27.81	26.67
21/6	16.00	32.05	26.32	28.88	25.93	28.20	26.68	27.81	26.67
21/6	17.00	31.97	26.18	28.95	26.02	28.53	26.70	27.81	26.66
21/6	18.00	31.95	26.07	28.87	26.00	29.07	26.72	27.82	26.66
21/6	19.00	31.97	26.11	28.54	25.37	29.21	26.41	27.82	26.65
21/6	20.00	31.97	26.16	28.40	25.32	29.43	26.20	27.82	26.65
21/6	21.00	32.02	26.31	28.91	25.91	29.60	26.05	27.83	26.65
21/6	22.00	32.01	26.31	28.82	25.53	29.50	25.78	27.83	26.64
21/6	23.00	31.91	26.22	28.66	26.29	29.35	25.72	27.83	26.64
22/6	0.0	31.79	25.97	28.37	26.01	29.46	25.86	27.83	26.64
22/6	1.00	31.78	25.99	28.14	25.30	29.50	25.80	27.82	26.63
22/6	2.00	31.84	26.01	27.42	24.30	29.30	25.56	27.82	26.63
22/6	3.00	31.79	26.13	27.93	25.46	29.49	25.89	27.82	26.62
22/6	4.00	31.67	26.03	28.26	25.66	29.43	25.94	27.81	26.62
22/6	5.00	31.66	26.01	28.27	25.42	29.42	25.92	27.81	26.62
22/6	6.00	31.71	25.92	27.71	24.56	29.46	25.83	27.81	26.61
22/6	7.00	31.69	25.99	27.89	24.80	28.16	24.60	27.80	26.61
22/6	8.00	31.66	26.02	28.44	25.00	28.07	24.44	27.80	26.61

A5.1.4 An Advancing Face Working District for the Second Week

The following are the temperature readings processed by Maneylaws (1988) of HQTD from the temperature survey undertaken at the advancing face working district on Level 1850 of Wearmouth Colliery.

Four thermohygrograph stations were positioned around the working district. Two stations were in the maingate; station 1. at the outbye end and station 2. at the inbye end. Two stations were in the tailgate; 3. at the inbye end and 4. at the outbye end.

Temperatures (°C)

		Station 1.		Station 2.		Station 3.		Station 4.	
Date	Time	D B	W B	D B	W B	D B	W B	D B	W B
22/6	11.00	31.98	26.14	28.55	26.30	28.00	26.37	27.81	26.67
22/6	12.00	31.75	26.00	28.58	26.38	28.07	26.38	27.82	26.68
22/6	13.00	31.81	26.03	28.72	26.60	28.15	26.50	27.83	26.67
22/6	14.00	32.06	26.13	28.56	26.34	28.08	26.45	27.84	26.66
22/6	15.00	32.01	26.11	28.35	25.94	27.97	26.32	27.84	26.65
22/6	16.00	31.89	26.02	28.26	26.19	28.28	26.57	27.85	26.63
22/6	17.00	31.85	25.91	28.22	26.21	28.62	26.53	27.86	26.62
22/6	18.00	31.80	25.80	28.33	26.41	29.13	26.41	27.87	26.61
22/6	19.00	31.71	25.80	28.57	26.67	29.38	26.14	27.88	26.62
22/6	20.00	31.62	25.87	28.62	26.56	29.53	25.95	27.89	26.63
22/6	21.00	31.65	25.85	28.36	25.95	29.58	25.80	27.91	26.64
22/6	22.00	31.74	25.85	28.24	25.44	29.36	25.52	27.92	26.66
22/6	23.00	31.76	25.82	28.35	26.12	28.01	24.40	27.93	26.67
23/6	0.0	31.73	26.08	28.42	26.27	28.76	25.35	27.95	26.68
23/6	1.00	31.77	26.18	28.50	26.34	29.40	26.40	27.96	26.69
23/6	2.00	31.75	25.99	28.57	26.36	30.01	26.57	27.98	26.71
23/6	3.00	31.67	25.92	28.63	26.38	30.22	26.49	27.99	26.72
23/6	4.00	31.67	26.05	28.55	26.28	29.67	25.81	28.00	26.73
23/6	5.00	31.79	26.09	28.49	26.24	28.92	25.17	28.02	26.75
23/6	6.00	31.69	26.13	28.60	26.41	28.84	26.15	28.03	26.76
23/6	7.00	31.70	26.14	28.71	26.53	28.64	25.66	28.05	26.77
23/6	8.00	31.71	26.14	28.81	26.63	28.61	27.02	28.06	26.79
23/6	9.00	31.71	26.15	28.80	26.42	28.11	26.56	28.07	26.80
23/6	10.00	31.86	26.17	28.72	26.01	27.96	26.37	28.09	26.81
23/6	11.00	32.05	26.28	28.69	26.42	28.09	26.45	28.10	26.83
23/6	12.00	31.96	26.48	28.70	26.54	28.15	26.52	28.11	26.83
23/6	13.00	31.75	26.28	28.71	26.71	28.22	26.60	28.12	26.84
23/6	14.00	31.70	26.17	28.73	26.80	28.34	26.65	28.14	26.85
23/6	15.00	31.76	26.15	28.69	26.70	28.32	26.63	28.15	26.86
23/6	16.00	31.89	26.30	28.56	26.52	28.29	26.53	28.16	26.86
23/6	17.00	31.91	26.17	28.17	26.01	28.53	26.51	28.17	26.87
23/6	18.00	31.90	26.13	28.11	25.49	28.86	26.42	28.18	26.88
23/6	19.00	31.96	26.09	28.22	25.54	29.09	26.16	28.19	26.89
23/6	20.00	31.95	26.14	28.31	25.95	29.25	26.17	28.21	26.90
23/6	21.00	31.81	26.14	28.35	25.97	29.32	26.09	28.22	26.90

23/6	22.00	31.78	26.13	28.37	25.94	29.38	26.06	28.23	26.91
23/6	23.00	31.79	26.07	28.39	25.91	28.93	25.84	28.24	26.92
24/6	0.0	31.68	26.07	28.42	25.92	28.42	26.67	28.25	26.93
24/6	1.00	31.60	25.96	28.45	25.94	28.49	26.81	28.26	26.93
24/6	2.00	31.55	25.97	28.49	25.97	28.75	27.07	28.28	26.94
24/6	3.00	31.55	26.04	28.52	25.97	28.59	26.87	28.29	26.95
24/6	4.00	31.60	26.03	28.43	25.81	28.35	26.63	28.30	26.96
24/6	5.00	31.63	25.98	28.22	25.53	28.66	26.65	28.31	26.97
24/6	6.00	31.43	25.89	27.87	25.16	28.70	26.17	28.32	26.97
24/6	7.00	31.58	26.13	27.90	24.83	27.97	25.24	28.33	26.98
24/6	8.00	31.84	26.18	28.26	25.07	27.96	26.04	28.34	26.99
24/6	9.00	31.76	26.27	28.55	25.45	28.29	26.15	28.34	26.98
24/6	10.00	31.73	26.18	28.64	25.95	28.30	25.61	28.33	26.97
24/6	11.00	31.75	26.09	28.67	26.00	28.29	26.36	28.33	26.96
24/6	12.00	31.80	26.34	28.64	25.93	28.20	26.31	28.32	26.95
24/6	13.00	31.70	26.14	28.60	26.00	28.19	26.22	28.31	26.95
24/6	14.00	31.76	26.16	28.58	25.99	28.06	26.08	28.31	26.94
24/6	15.00	31.67	26.24	28.62	26.10	28.05	26.22	28.30	26.93
24/6	16.00	31.73	26.20	28.68	26.14	28.28	26.44	28.30	26.92
24/6	17.00	31.78	26.19	28.75	26.05	28.51	26.52	28.29	26.91
24/6	18.00	31.81	26.25	28.87	25.82	28.73	26.32	28.28	26.90
24/6	19.00	31.80	26.17	28.91	25.70	28.90	25.94	28.28	26.90
24/6	20.00	31.65	26.03	28.64	26.04	28.86	25.56	28.27	26.89
24/6	21.00	31.58	26.01	28.26	25.79	28.78	25.42	28.27	26.88
24/6	22.00	31.63	26.02	28.33	25.60	28.89	25.55	28.26	26.87
24/6	23.00	31.70	26.00	28.70	25.88	29.01	25.86	28.25	26.86
25/6	0.0	31.60	25.85	28.99	26.66	29.12	26.01	28.25	26.85
25/6	1.00	31.40	25.62	29.22	26.90	29.06	25.74	28.24	26.85
25/6	2.00	31.25	25.41	29.28	26.91	29.04	25.56	28.24	26.84
25/6	3.00	31.10	25.18	29.02	26.58	29.03	25.59	28.23	26.83
25/6	4.00	31.02	25.05	28.72	26.28	28.91	25.54	28.22	26.82
25/6	5.00	30.36	24.39	28.46	26.06	28.87	25.70	28.22	26.81
25/6	6.00	29.71	23.91	28.31	25.94	28.91	25.52	28.21	26.80
25/6	7.00	29.37	23.94	28.26	25.90	29.09	25.82	28.20	26.80
25/6	8.00	29.43	24.12	28.26	25.95	28.74	25.54	28.20	26.79
25/6	9.00	29.69	24.37	28.19	25.81	28.43	24.97	28.20	26.78
25/6	10.00	29.97	24.60	28.18	25.51	28.51	26.04	28.19	26.78
25/6	11.00	30.32	24.68	28.00	25.03	28.53	25.88	28.19	26.77
25/6	12.00	30.54	24.74	27.22	24.13	28.33	25.36	28.19	26.77
25/6	13.00	30.65	24.74	26.51	23.45	28.27	25.27	28.19	26.77
25/6	14.00	30.71	24.70	26.31	24.06	28.25	25.36	28.19	26.76
25/6	15.00	30.73	24.65	26.65	24.49	28.24	25.42	28.19	26.76
25/6	16.00	30.70	24.58	27.00	24.64	28.23	25.39	28.19	26.75
25/6	17.00	30.60	24.47	27.04	24.49	28.21	25.34	28.19	26.75
25/6	18.00	30.49	24.36	27.03	24.63	28.20	25.29	28.19	26.75
25/6	19.00	30.38	24.25	27.02	24.74	28.19	25.24	28.19	26.74
25/6	20.00	30.27	24.13	27.00	24.74	28.18	25.19	28.18	26.74
25/6	21.00	30.16	24.02	26.99	24.74	28.17	25.17	28.18	26.74
25/6	22.00	30.05	23.91	26.98	24.75	28.16	25.16	28.18	26.73
25/6	23.00	29.94	23.80	26.99	24.77	28.15	25.14	28.18	26.73
26/6	0.0	29.83	23.68	27.00	24.79	28.13	25.12	28.18	26.72
26/6	1.00	29.72	23.57	27.01	24.81	28.12	25.11	28.18	26.72
26/6	2.00	29.61	23.46	27.03	24.83	28.11	25.09	28.18	26.72
26/6	3.00	29.50	23.35	27.04	24.85	28.10	25.08	28.18	26.71
26/6	4.00	29.39	23.24	27.06	24.87	28.09	25.06	28.18	26.71
26/6	5.00	29.28	23.12	27.07	24.89	28.11	25.07	28.18	26.70
26/6	6.00	29.17	23.03	27.02	24.78	28.20	25.14	28.17	26.70
26/6	7.00	29.16	23.25	26.88	24.68	28.30	25.21	28.16	26.69
26/6	8.00	29.58	23.77	26.77	24.62	28.40	25.28	28.16	26.68
26/6	9.00	30.08	24.23	26.70	24.42	27.89	24.52	28.15	26.67
26/6	10.00	30.48	24.50	26.70	24.50	27.27	24.09	28.14	26.66

26/6	11.00	30.63	24.44	26.72	24.53	27.10	25.09	28.14	26.65
26/6	12.00	30.69	24.37	26.75	24.40	27.04	25.17	28.13	26.64
26/6	13.00	30.72	24.36	26.77	24.06	27.00	25.12	28.12	26.63
26/6	14.00	30.72	24.33	26.80	24.49	26.96	25.07	28.11	26.63
26/6	15.00	30.70	24.29	26.84	24.61	26.91	25.02	28.11	26.62
26/6	16.00	30.67	24.25	26.89	24.63	26.87	24.97	28.10	26.61
26/6	17.00	30.65	24.22	26.94	24.66	26.82	24.92	28.09	26.60
26/6	18.00	30.62	24.18	26.99	24.69	26.83	24.92	28.08	26.59
26/6	19.00	30.60	24.14	27.05	24.72	26.88	24.98	28.08	26.58
26/6	20.00	30.57	24.10	27.10	24.75	26.96	25.05	28.07	26.57
26/6	21.00	30.55	24.07	27.15	24.77	27.17	25.21	28.06	26.56
26/6	22.00	30.52	24.03	27.20	24.80	27.39	25.37	28.05	26.55
26/6	23.00	30.50	23.99	27.26	24.84	27.26	24.89	28.05	26.55
27/6	0.0	30.50	24.11	27.48	25.01	27.28	24.60	28.04	26.54
27/6	1.00	30.74	24.84	27.61	25.31	27.36	24.67	28.03	26.53
27/6	2.00	30.84	25.18	27.70	25.40	27.37	25.54	28.02	26.52
27/6	3.00	30.91	25.14	27.80	25.45	27.50	25.68	28.01	26.51
27/6	4.00	31.10	25.40	27.87	25.48	27.75	25.90	28.01	26.51
27/6	5.00	31.22	25.46	27.82	25.42	27.84	25.94	28.00	26.50
27/6	6.00	31.24	25.23	27.98	25.47	27.77	25.42	27.99	26.49
27/6	7.00	31.26	25.68	28.28	25.60	27.89	25.76	27.98	26.49
27/6	8.00	31.29	25.74	28.62	25.73	28.00	26.21	27.97	26.48
27/6	9.00	31.34	25.64	28.85	25.75	27.94	26.08	27.96	26.47
27/6	10.00	31.38	25.72	29.08	25.76	27.85	26.03	27.95	26.46
27/6	11.00	31.35	25.66	29.06	25.56	27.78	25.83	27.95	26.46
27/6	12.00	31.31	25.52	28.88	25.22	27.63	25.38	27.94	26.45
27/6	13.00	31.28	25.55	28.74	25.02	27.52	25.68	27.93	26.44
27/6	14.00	31.30	25.65	28.55	24.72	27.40	25.58	27.92	26.43
27/6	15.00	31.38	25.71	27.91	25.24	27.38	25.66	27.91	26.43
27/6	16.00	31.40	25.64	28.01	25.08	27.42	25.69	27.90	26.42
27/6	17.00	31.38	25.57	28.33	25.57	27.48	25.72	27.90	26.41
27/6	18.00	31.31	25.63	28.44	25.72	27.60	25.85	27.89	26.41
27/6	19.00	31.18	25.75	28.36	25.78	27.66	25.92	27.88	26.40
27/6	20.00	31.27	25.61	28.30	25.79	27.82	26.06	27.88	26.40
27/6	21.00	31.12	25.56	28.36	25.99	27.98	25.86	27.88	26.41
27/6	22.00	31.09	25.63	28.44	26.04	28.06	25.77	27.89	26.41
27/6	23.00	31.13	25.61	28.59	26.12	28.31	26.38	27.90	26.42
28/6	0.0	31.11	25.53	28.74	26.18	28.49	26.08	27.90	26.43
28/6	1.00	31.07	25.56	28.83	26.19	28.29	25.49	27.91	26.43
28/6	2.00	31.14	25.79	28.84	26.14	27.99	25.04	27.91	26.44
28/6	3.00	31.26	25.93	28.82	26.10	28.04	25.92	27.92	26.45
28/6	4.00	31.24	25.85	28.81	26.18	28.08	26.27	27.93	26.46
28/6	5.00	31.18	25.75	28.83	26.27	28.12	26.29	27.93	26.46
28/6	6.00	31.16	25.73	28.85	26.32	27.99	25.88	27.94	26.47
28/6	7.00	31.23	25.92	28.87	26.36	27.97	26.31	27.94	26.48
28/6	8.00	31.22	25.91	28.96	26.49	28.19	26.60	27.95	26.48
28/6	9.00	31.20	25.90	29.14	26.57	28.08	26.38	27.96	26.49
28/6	10.00	31.20	25.93	29.37	26.48	27.85	26.12	27.96	26.50
28/6	11.00	31.30	25.80	29.53	26.25	27.75	25.94	27.97	26.51
28/6	12.00	31.24	25.73	29.59	26.02	27.70	25.92	27.97	26.51
28/6	13.00	30.85	25.56	29.49	25.72	27.63	25.93	27.98	26.52
28/6	14.00	30.89	25.65	29.08	25.21	27.58	25.95	27.99	26.52
28/6	15.00	31.10	25.81	28.57	25.44	27.52	25.82	28.00	26.53
28/6	16.00	31.17	25.91	28.68	25.77	27.61	25.87	28.01	26.53
28/6	17.00	31.18	25.88	28.80	25.70	28.13	26.20	28.02	26.53
28/6	18.00	31.15	25.82	28.88	25.61	28.44	26.06	28.03	26.54
28/6	19.00	31.10	25.84	28.79	25.98	28.58	25.88	28.04	26.54
28/6	20.00	31.02	25.75	28.29	26.15	28.61	25.94	28.05	26.54
28/6	21.00	30.98	25.68	27.57	25.30	28.49	25.70	28.06	26.55
28/6	22.00	31.06	25.60	27.24	24.64	28.40	25.60	28.07	26.55
28/6	23.00	31.16	25.66	27.42	24.67	28.41	25.60	28.08	26.56
29/6	0.0	31.05	25.77	27.91	25.19	28.40	25.45	28.10	26.57
29/6	1.00	30.82	25.65	28.25	25.88	28.38	25.34	28.11	26.58
29/6	2.00	30.86	25.73	28.39	26.19	28.47	25.37	28.12	26.58
29/6	3.00	30.95	25.79	28.48	26.34	28.61	25.91	28.14	26.59
29/6	4.00	31.02	25.87	28.64	26.47	28.97	26.18	28.15	26.60

29/ 6	5.00	31.15	25.80	28.72	26.43	28.62	25.79	28.16	26.61
29/ 6	6.00	31.32	26.09	28.79	26.43	28.17	25.87	28.17	26.62
29/ 6	7.00	31.37	26.17	28.89	26.60	27.89	26.27	28.19	26.63
29/ 6	8.00	31.29	25.94	28.93	26.70	27.95	26.35	28.20	26.63

A5.2 WHITEMOOR COLLIERY

A5.2.1 A Retreating Face Working District for the First Week

The following are the temperature readings processed by Maneylaws (1988) of HQTD from the temperature survey undertaken at the retreating face working district roadway of Whitemoor Colliery.

Four thermohygrograph stations were positioned around the working district. Two stations were in the maingate; station 1. at the outbye end and station 2. at the inbye end. Two stations were in the tailgate; 3. at the inbye end and 4. at the outbye end.

Temperatures (°C)

		Station 2.		Station 3.		Station 4.	
Date	Time	D B	W B	D B	W B	D B	W B
2/11	12.000	24.32	18.83	29.82	27.85	30.01	26.93
2/11	13.000	24.16	18.17	29.83	27.67	29.85	26.60
2/11	14.000	24.02	17.66	29.71	27.13	29.57	25.88
2/11	15.000	23.91	17.73	29.70	26.94	29.44	25.45
2/11	16.000	24.00	17.37	29.45	27.06	29.62	25.73
2/11	17.000	24.03	17.77	29.33	27.13	29.73	25.23
2/11	18.000	23.65	17.09	29.24	26.88	29.48	24.54
2/11	19.000	23.35	17.15	29.02	26.24	29.05	24.48
2/11	20.000	23.23	16.90	28.84	25.79	28.74	23.78
2/11	21.000	23.25	16.46	28.92	25.67	28.63	23.58
2/11	22.000	23.34	16.23	29.30	25.87	28.78	23.73
2/11	23.000	23.39	16.08	29.40	25.76	29.01	23.47
3/11	0.0	23.43	15.97	29.27	26.30	29.09	23.10
3/11	1.000	23.36	16.87	28.93	26.54	29.18	22.69
3/11	2.000	23.25	16.83	28.91	26.15	29.45	22.82
3/11	3.000	23.02	16.23	28.71	26.77	28.71	22.62
3/11	4.000	22.81	16.11	28.16	25.88	28.22	23.12
3/11	5.000	22.66	15.80	27.90	25.43	28.08	22.52
3/11	6.000	22.50	15.43	27.69	24.98	27.88	22.55
3/11	7.000	22.35	15.16	27.53	24.58	27.73	22.46
3/11	8.000	22.27	14.90	27.46	24.28	27.64	21.99
3/11	9.000	22.07	14.55	27.42	24.06	27.63	21.67
3/11	10.000	21.97	14.41	27.44	23.96	27.66	21.40
3/11	11.000	21.99	14.40	27.47	23.87	27.75	21.27
3/11	12.000	22.30	14.64	27.70	23.98	27.88	21.21
3/11	13.000	22.64	15.02	28.02	24.17	28.02	21.21
3/11	14.000	22.77	15.61	28.63	24.86	28.11	21.12

3/11	15.000	22.88	17.00	28.38	25.78	28.23	21.07
3/11	16.000	23.02	16.76	28.20	26.24	28.45	21.14
3/11	17.000	23.18	16.47	28.47	26.72	28.84	21.52
3/11	18.000	23.35	17.29	28.83	27.52	28.54	21.95
3/11	19.000	23.20	17.48	28.87	27.38	28.15	22.59
3/11	20.000	23.06	16.79	28.57	26.70	28.17	22.41
3/11	21.000	22.84	16.12	28.24	26.03	28.26	23.84
3/11	22.000	22.82	15.76	28.10	25.59	28.36	23.48
3/11	23.000	22.88	15.56	28.26	25.42	28.49	23.17
4/11	0.0	22.89	15.37	28.55	25.44	28.73	22.99
4/11	1.000	22.88	16.36	28.66	25.35	29.06	22.93
4/11	2.000	22.70	17.24	28.81	27.21	28.88	22.53
4/11	3.000	22.73	17.03	29.07	27.71	28.89	22.48
4/11	4.000	22.86	17.58	28.81	27.56	28.73	24.49
4/11	5.000	22.59	17.04	28.83	27.92	28.31	24.25
4/11	6.000	22.83	16.69	28.71	27.41	28.35	24.64
4/11	7.000	23.17	16.50	28.13	26.45	28.59	24.38
4/11	8.000	23.42	16.56	28.03	26.35	28.61	23.87
4/11	9.000	23.63	17.40	28.45	26.86	28.67	23.64
4/11	10.000	23.90	17.73	28.83	27.82	28.83	24.61
4/11	11.000	23.94	18.23	28.86	28.27	28.99	25.49
4/11	12.000	24.01	17.73	28.99	28.05	29.12	25.57
4/11	13.000	23.71	17.52	29.31	28.27	29.19	25.23
4/11	14.000	23.60	18.18	29.22	28.18	29.24	25.70
4/11	15.000	23.62	18.21	29.29	28.56	29.30	25.87
4/11	16.000	23.42	18.18	29.35	28.60	29.37	25.89
4/11	17.000	23.27	18.00	29.51	28.78	29.63	26.24
4/11	18.000	23.04	17.99	29.65	29.08	29.66	26.49
4/11	19.000	22.71	17.15	29.68	29.12	29.37	26.14
4/11	20.000	22.40	16.34	29.70	28.84	28.92	25.30
4/11	21.000	22.29	15.76	29.70	28.51	28.74	24.70
4/11	22.000	22.41	15.54	29.51	27.97	28.87	24.42
4/11	23.000	22.49	15.41	29.28	27.40	29.00	24.15
5/11	0.0	22.54	15.32	29.07	26.86	29.13	23.88
5/11	1.000	22.57	15.47	28.96	26.50	29.32	23.70
5/11	2.000	22.57	17.30	28.92	26.21	29.46	23.51
5/11	3.000	22.74	17.46	29.14	26.18	29.46	25.09
5/11	4.000	22.43	16.87	29.30	27.98	29.29	25.99
5/11	5.000	21.95	16.43	29.44	28.84	27.99	24.56
5/11	6.000	21.78	15.78	29.60	28.68	27.22	23.62
5/11	7.000	21.72	15.31	29.58	28.74	26.94	22.86
5/11	8.000	21.49	14.87	29.57	28.37	26.72	22.21
5/11	9.000	21.22	14.44	29.18	27.55	26.57	21.71
5/11	10.000	20.98	14.15	28.64	26.63	26.41	21.54
5/11	11.000	20.74	13.90	28.16	25.89	26.26	21.44
5/11	12.000	20.62	13.81	28.02	25.54	26.16	21.42
5/11	13.000	20.62	13.90	27.97	25.29	26.10	21.61
5/11	14.000	20.62	13.99	27.92	25.06	26.05	21.39
5/11	15.000	20.62	14.09	27.87	24.87	25.99	21.13
5/11	16.000	20.63	14.21	27.80	24.77	25.94	20.92
5/11	17.000	20.63	14.33	27.71	24.80	25.88	20.70
5/11	18.000	20.63	14.39	27.61	24.57	25.82	20.51
5/11	19.000	20.63	14.45	27.51	24.33	25.77	20.35
5/11	20.000	20.63	14.39	27.42	24.10	25.71	20.22
5/11	21.000	20.64	14.30	27.31	23.96	25.66	20.13
5/11	22.000	20.64	14.34	27.21	23.86	25.62	20.02
5/11	23.000	20.64	14.39	27.11	23.76	25.60	19.89

A5.2.2 A Retreating Face Working District for the Second Week

The following are the temperature readings processed by Maneylaws (1988) of HQTD from the temperature survey undertaken at the retreating face working district roadway of Whitemoor Colliery.

Four thermohygrograph stations were positioned around the working district. Two stations were in the maingate; station 1. at the outbye end and station 2. at the inbye end. Two stations were in the tailgate; 3. at the inbye end and 4. at the outbye end.

Temperatures (°C)

		Station 1.		Station 2.		Station 3.		Station 4.	
Date	Time	D B	W B	D B	W B	D B	W B	D B	W B
9/11	13.000	21.24	18.43	24.11	20.31	29.55	27.12	29.64	26.54
9/11	14.000	21.11	17.86	23.90	19.97	29.57	27.67	29.66	26.94
9/11	15.000	21.46	18.32	23.88	19.59	29.45	27.48	29.74	26.93
9/11	16.000	22.05	18.79	23.95	19.75	29.27	27.17	29.71	26.79
9/11	17.000	21.58	18.65	24.02	19.93	29.23	27.44	29.64	26.78
9/11	18.000	21.65	18.26	24.24	19.61	29.15	27.13	29.53	26.89
9/11	19.000	21.68	17.90	24.53	19.40	28.84	26.29	29.37	26.35
9/11	20.000	21.46	17.47	24.26	18.93	28.46	25.40	29.21	25.77
9/11	21.000	21.46	17.30	23.86	18.42	28.08	24.60	29.06	25.18
9/11	22.000	21.50	17.09	23.57	18.05	27.97	24.14	28.90	24.65
9/11	23.000	21.44	16.87	23.29	17.71	28.03	23.93	28.75	24.18
10/11	0.0	21.45	16.60	23.03	17.39	28.19	23.87	28.60	23.72
10/11	1.000	21.25	16.44	22.99	17.42	27.85	23.24	28.61	23.44
10/11	2.000	21.21	16.65	23.11	17.61	27.82	23.13	28.70	23.25
10/11	3.000	21.14	16.49	23.38	17.81	28.32	23.45	28.85	23.16
10/11	4.000	21.41	17.19	23.69	18.74	28.56	23.62	29.03	23.18
10/11	5.000	21.38	17.49	23.86	18.94	28.36	24.61	28.98	23.05
10/11	6.000	21.57	17.35	23.83	18.44	28.15	24.95	28.75	22.71
10/11	7.000	21.31	16.72	23.82	18.11	28.04	24.92	28.70	23.51
10/11	8.000	21.60	17.04	23.87	18.71	27.94	24.96	28.69	24.31
10/11	9.000	22.00	17.53	23.96	18.58	28.12	24.67	28.87	24.27
10/11	10.000	22.28	17.39	24.10	18.69	28.32	24.97	29.10	24.80
10/11	11.000	22.12	17.55	24.29	19.86	28.84	26.74	29.29	24.60
10/11	12.000	22.41	18.32	24.31	19.86	28.99	26.57	29.42	24.86
10/11	13.000	22.87	18.88	24.32	20.49	28.98	27.13	29.48	26.18
10/11	14.000	22.48	18.06	24.35	20.62	29.23	27.37	29.52	26.43
10/11	15.000	22.42	19.07	24.39	20.24	29.34	27.06	29.51	26.76
10/11	16.000	22.16	18.50	24.43	20.64	29.31	26.84	29.45	26.59
10/11	17.000	22.28	18.99	24.47	20.67	29.29	27.34	29.39	26.21
10/11	18.000	21.76	18.63	24.51	20.37	29.28	26.93	29.31	26.68
10/11	19.000	21.82	18.44	24.53	19.84	29.02	26.24	29.23	26.46
10/11	20.000	21.86	18.00	24.47	19.39	28.67	25.47	29.12	26.00
10/11	21.000	21.69	17.50	24.38	18.95	28.36	24.86	28.98	25.46
10/11	22.000	21.55	17.12	24.18	18.57	28.20	24.47	28.86	24.90
10/11	23.000	21.53	16.87	23.95	18.19	28.42	24.40	28.99	24.68
11/11	0.0	21.80	16.86	23.83	17.96	28.87	25.48	29.23	24.63
11/11	1.000	22.41	17.16	23.98	19.27	29.05	26.39	29.50	24.61
11/11	2.000	22.67	18.07	24.15	19.27	29.23	26.78	29.77	25.28
11/11	3.000	22.46	18.13	24.24	19.18	29.37	26.59	29.91	26.66
11/11	4.000	22.21	17.33	24.30	19.22	29.48	26.30	30.23	26.77
11/11	5.000	22.40	17.26	24.47	18.93	29.19	25.57	29.95	26.46
11/11	6.000	21.82	16.87	24.56	18.95	28.87	24.83	29.52	26.12
11/11	7.000	21.43	16.44	24.30	18.16	28.83	25.20	29.49	25.71

11/11	8.000	21.36	15.86	24.12	17.71	28.98	26.29	29.54	25.29
11/11	9.000	21.53	15.55	24.01	17.62	29.13	26.39	29.61	24.95
11/11	10.000	21.42	15.15	24.04	18.23	29.29	26.76	29.77	25.38
11/11	11.000	21.16	14.78	24.27	18.80	29.47	26.70	29.93	25.94
11/11	12.000	21.14	15.56	24.48	18.94	29.34	27.12	29.86	26.12
11/11	13.000	21.16	15.82	24.46	18.93	29.41	27.15	29.78	26.21
11/11	14.000	21.21	16.15	24.48	18.86	29.44	26.98	29.77	26.33
11/11	15.000	21.66	16.27	24.52	19.33	29.44	27.14	29.83	26.43
11/11	16.000	21.41	16.16	24.47	19.14	29.44	27.08	29.89	26.81
11/11	17.000	21.00	15.73	24.39	19.16	29.51	26.67	29.97	26.73
11/11	18.000	20.93	15.77	24.37	19.10	29.62	26.19	30.04	26.78
11/11	19.000	21.01	15.91	24.37	19.11	29.68	25.74	29.85	26.60
11/11	20.000	20.94	15.78	24.28	18.77	29.61	25.23	29.59	26.31
11/11	21.000	20.78	15.54	24.05	18.10	29.18	24.53	29.34	25.63
11/11	22.000	20.62	15.38	23.67	17.28	28.72	23.83	29.09	24.89
11/11	23.000	20.41	14.81	23.36	16.61	28.26	23.13	28.84	24.23
12/11	0.0	20.13	14.10	23.09	16.07	27.84	22.52	28.62	23.64
12/11	1.000	19.95	13.51	23.01	15.80	27.61	22.25	28.44	23.17
12/11	2.000	20.12	13.38	22.99	15.66	27.41	22.02	28.28	22.72
12/11	3.000	19.67	12.88	22.87	15.57	27.31	21.88	28.14	22.31
12/11	4.000	19.53	12.71	22.38	15.47	27.29	21.81	28.02	21.99
12/11	5.000	19.60	13.40	22.15	15.44	27.18	21.65	27.92	21.72
12/11	6.000	19.72	13.57	22.03	15.39	27.07	21.47	27.82	21.50
12/11	7.000	19.80	13.76	21.89	15.25	26.97	21.31	27.74	21.32
12/11	8.000	19.84	13.83	21.91	15.17	26.89	21.21	27.66	21.15
12/11	9.000	19.99	13.87	21.93	15.10	26.81	21.14	27.60	21.00
12/11	10.000	20.47	14.00	21.90	15.02	26.75	21.08	27.57	20.88
12/11	11.000	20.35	13.69	21.88	14.93	26.68	21.03	27.55	20.77
12/11	12.000	19.87	13.18	21.85	14.86	26.62	20.99	27.53	20.66
12/11	13.000	19.85	13.08	21.80	14.85	26.59	20.97	27.50	20.55
12/11	14.000	19.95	13.09	21.74	14.87	26.61	20.98	27.47	20.44
12/11	15.000	20.12	13.21	21.68	14.89	26.48	20.85	27.37	20.32
12/11	16.000	20.34	13.46	21.61	14.93	26.28	20.65	27.25	20.18
12/11	17.000	20.47	13.95	21.54	14.96	26.12	20.50	27.08	20.02
12/11	18.000	20.17	13.82	21.48	14.99	26.08	20.49	26.91	19.86
12/11	19.000	19.98	13.67	21.47	15.03	26.06	20.50	26.76	19.71
12/11	20.000	19.84	13.52	21.47	15.07	26.03	20.51	26.68	19.60
12/11	21.000	19.74	13.41	21.48	15.10	26.01	20.52	26.62	19.50
12/11	22.000	19.76	13.37	21.49	15.13	25.97	20.46	26.55	19.40
12/11	23.000	19.81	13.42	21.52	15.13	25.93	20.38	26.48	19.29
13/11	0.0	19.89	13.49	21.55	15.13	25.90	20.29	26.41	19.29