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# **CLIMSIM™**

**(VERSION 2.0)**

## **CLIMATIC SIMULATION PROGRAM USER'S MANUAL**



**MINE  
VENTILATION  
SERVICES, INC.**

CLIMSIM USES

Airway Data

Length (m)  
Depth - inlet and outlet (m)  
Cross-section Area (m<sup>2</sup>)  
Perimeter (m)  
Friction Coefficient (kg/m<sup>3</sup>)  
Wetness (% moist surface)  
Age at intake and outlet (days)

Air Conditions at intake

Quantity (m<sup>3</sup>/sec)  
Pressure (kPa)  
Dry bulb and Wet bulb (°C)

Rock Conditions

Virgin rock temperature (°C)  
Geothermal Step (m/°C)  
Thermal Conductivity W/m°C  
Diffusivity (m<sup>2</sup>/sec)  
Specific heat (J/kg°C)

Additional Heat Sources

TAKING INTO ACCOUNT

Sensible heat  
Latent heat  
  
Strata heat  
(empirical heat transfer)  
Wet and dry surfaces

Air pressure  
friction  
elevation

TO PRODUCE

Distance from intake  
Dry bulb temperature (°C)  
Wet bulb temperature °C  
Moisture content (g/kg)  
Relative humidity (%)  
Pressure (kPa)  
Density (kg/m<sup>3</sup>)  
Air cooling power (w/m<sup>2</sup>)

Effective temperature (°C)  
Wet bulb globe (°C)  
Enthalpy (kJ/kg)  
Sigma heat (kJ/kg)  
Drywall rock temperature (°C)  
Virgin rock temperature (°C)

Evaporation/condensation

## FORWARD

The growing availability of microcomputers on mine sites has led to a demand for user-friendly software packages to assist in the design and control of mine systems and operations. CLIMSIM (climatic simulation) has been developed as a rapid means of predicting the climatic conditions that will exist along any mine shaft, slope or airway. Version (2.0) of CLIMSIM, described in this manual, is made easy to use through a series of interconnected menus that permit a completely interactive mode of operation including screen and hard copy graphical output.

The system takes into account the effects of autocompression, strata heat, airway wetness, diesel and electrical machinery, cooling plant, and any other sources of sensible and latent heat specified by the user. The program also deals with the variation in age of the excavation along its length. The theoretical basis of CLIMSIM (2.0) assumes radial heat conduction through the strata towards the airway. Therefore, the program is not intended for configurations that depart significantly from radial heat flow.

CLIMSIM (2.0) has been written for the IBM PC XT, AT and compatible machines. It has been developed for use by engineers responsible for the design and maintenance of ventilation and air conditioning systems in underground openings, and does not require a knowledge of computer programming.

This User's Manual gives step by step guidance on commissioning the system, data preparation, and operation.

We wish you success in your use of the CLIMSIM (2.0) software.

Malcolm J. McPherson  
President  
Mine Ventilation Services

## CONTENTS

### LIST OF ILLUSTRATIONS

#### INTRODUCTION

1.	OVERVIEW OF CLIMSIM (2.0) .....	3
1.1	Description of CLIMSIM (2.0) .....	3
1.2	Capabilities and Features of CLIMSIM (2.0) .....	4
1.3	Hardware Requirements .....	5
2.	STRUCTURE AND INPUT REQUIREMENTS .....	7
2.1	Initial Data Input .....	8
2.1.1	Configuration File (CONFIG) .....	8
2.1.2	Climatic Output Parameters .....	9
2.1.3	Input Data .....	10
2.1.3.1	Description of airway .....	10
2.1.3.2	Ventilation conditions at intake .....	14
2.1.3.3	Thermal parameters .....	15
2.1.3.4	Additional heat sources .....	17
2.1.3.5	Distance between temperature outputs .....	20
2.2	List Input Data .....	21
2.3	Execution and Output .....	22
2.4	Graphics Output .....	24
2.4.1	Graphics Menu .....	24
2.4.2	Redraw Graph to Own Axes .....	25
2.4.3	Plot Graph on Plotter .....	25
2.5	Data Modification .....	26
2.5.1	Description of Airway .....	26
2.5.2	Inlet Conditions to Airway .....	27
2.5.3	Rock Thermal Parameters .....	27
2.5.4	Spot and Linear Heat Sources .....	28
2.5.6	Re-enter Data from Beginning .....	30
2.6	Data File Management .....	30
2.6.1	List Data Files on Drives .....	31
2.6.2	Read Data File from Drive .....	31
2.6.3	Delete Data Files .....	31
2.6.4	Save Current Input Data .....	31
3.	INSTALLATION AND FILE MANAGEMENT .....	33
3.1	Installation .....	33

## CONTENTS (Continued)

3.1.1	Floppy Drive System .....	33
3.1.2	Fixed Disk System .....	34
3.1.2.1	Set up sub-directory .....	35
3.1.2.2	Copying CLIMSIM (2.0) files to your Sub-directory .....	35
3.1.2.3	Supplying the key - the install option .....	36
3.1.3	Backup and Care of the CLIMSIM (2.0) Diskette...	37
3.2	File Management .....	38
4.	PROGRAM OPERATION AND USE .....	40
4.1	Initial Data Entry .....	40
4.2	Viewing and Saving Simulation Results .....	41
4.3	Modifying and Saving Input Data .....	42
4.4	Some Practical Observations on Data Acquisition and Correlation Trials .....	43
4.4.1	Uncertain Input Parameters .....	44
4.4.2	Correlation Trials .....	46
5.	EXAMPLE .....	49
5.1	Introduction .....	49
5.2	Layout of Airflow Route .....	50
5.3	CLIMSIM Runs (2.0) .....	51
5.3.1	Downcast Shaft .....	51
5.3.2	Level .....	59
5.3.3	Conveyor Slope .....	72
5.4	Concluding Comments .....	80
6.	PROGRAM LISTING .....	81
APPENDIX 1:	Table of Conversion Factors Between Imperial and SI Units .....	82

## LIST OF ILLUSTRATIONS

### TABLES

2.1	Values of Airway Friction Coefficients .....	13
2.2	Typical Values of Thermal Properties .....	16
5.1	Input Data for Shaft .....	53
5.2	Tabular Output for the Downcast Shaft .....	54
5.3	Input Data for the Level .....	64
5.4	Tabular Output for Level .....	65
5.5	Input Data for Conveyor Slope .....	76
5.6	Tabular Output for the Conveyor Slope .....	77

### FIGURES

2.1	Structure of CLIMSIM (2.0) .....	7A
2.2	Initial data Input .....	8A
2.3	Data Modification .....	26A
2.4	Data File Management .....	30A
5.1	Airflow Route Chosen for Analysis .....	50
5.2	Air Temperature in Shaft .....	55
5.3	Barometric Pressure in Shaft .....	56
5.4	Relative Humidity in Shaft .....	57
5.5	Distribution of Heat Sources in the Level .....	59
5.6	Air Temperatures in Level .....	66
5.7	Moisture Content of Air in Level .....	67
5.8	Relative Humidity in Level .....	68
5.9	Sigma Heat of Air in Level .....	69
5.10	Temperature of Dry Rock Surface in Level .....	70
5.11	Air Cooling Power in Level .....	71

LIST OF ILLUSTRATIONS (Continued)

5.12 Locations of Additional Heat Sources in Conveyor Slope .....72  
5.13 Air Temperature in Conveyor Slope .....78  
5.14 Relative Humidity in Conveyor Slope .....79

## INTRODUCTION

The CLIMSIM (Version 2.0) program is designed to assist mine environmental engineers in the planning of sub-surface ventilation and cooling systems. Given data that describes the characteristics of an airway, the surrounding strata, the inlet air conditions, and the locations of heat sources or cooling units, CLIMSIM (2.0) will produce listings and graphical plots of the climatic variations along the airway.

The CLIMSIM (2.0) software has been developed specifically for the IBM PC XT and AT microcomputers and compatible machines. The full hardware requirements are given in Section 1.3 of the manual. The system is supplied on a 5 1/4 inch double density diskette.

The CLIMSIM (2.0) program is completely interactive. Simply enter the data when the computer asks for it. There are plenty of opportunities to amend data if you make a mistake or wish to modify an airway model.

On obtaining a new program there is a very natural impatience to load it into the machine and to start pressing buttons, just to see what happens. However, we would like to make two suggestions to save yourself time and to familiarize yourself with the system. First, read Sections 1, 3 and 4 of this manual carefully. Section 2 contains details of individual menu items and input requirements and may be used for reference and further reading. Second, sit at the keyboard and reproduce the example given in Section 5. The time spent on these preparatory exercises will repay itself many times over as you progress in your experience of using CLIMSIM (2.0).

If you have any questions regarding CLIMSIM (2.0) or any of our other software systems, or if you would like some special features built into a customized version of the program, then please contact us at:

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## 1. OVERVIEW OF CLIMSIM (Version 2.0)

This introductory section describes the applications and features of CLIMSIM (2.0) and the required hardware to take full advantage of the program.

Section 2 describes the CLIMSIM (2.0) structure, explaining in detail each menu option and required inputs. Section 2 may be used as a reference manual. Sections 3 and 4 are a guide to the successful installation and use of CLIMSIM (2.0) and Section 5 presents an example of a CLIMSIM (2.0) run.

### 1.1 Description of CLIMSIM (Version 2.0)

The purpose of CLIMSIM (2.0) is to provide a rapid means of predicting the variation in psychrometric and thermodynamic properties of the air and heat stress indices at chosen intervals along any underground shaft, slope or airway, given the inlet conditions and information relating to those parameters that govern the underground climate.

The program divides the airway length into finite elements of 20 m or less. Within each length, interactive numerical procedures are employed to establish heat balances between strata heat arriving at the rock surface and the heat transferred to the general body airstream across the boundary layer at the rock/air interface, taking full account of the airway age. Both wet and dry surfaces are considered and evaporation/condensation processes are taken fully into account. The variation in air pressure due to frictional flow and changes in elevation are also handled by the program together with the corresponding changes in wet bulb and dry bulb temperatures.

In addition to strata heat, artificial sources of sensible and latent heat or cooling from machinery or heat exchangers may also be investigated by CLIMSIM (2.0). Such sources can be inserted as "spot sources" at fixed locations and "linear sources" extended over a specified length of the airway.

The results are produced as a tabulated listing which describes the variation of ten climatic/thermodynamic parameters along the airway, and also as graphical plots of wet and dry bulb temperature or any other computed parameter.

CLIMSIM (2.0) is suitable for design engineers involved in conceptual and detailed design of ventilation and cooling systems for subsurface structures. It is an interactive menu-driven program and requires no knowledge of computer programming or data file creation. CLIMSIM (2.0) prompts the user for the required data and includes internal data editing and data saving capabilities. The portability of CLIMSIM (2.0) enables it to be used on site by mine engineers for rapid evaluation of the underground climate.

#### 1.2 Capabilities and Features of CLIMSIM (Version 2.0)

- o Interactive Operation - CLIMSIM (2.0) is controlled interactively by the user through a small number of simple menus.
  
- o Complete Heat Load Consideration - Sensible and latent heat loads are considered from both concentrated and extended heat and refrigeration sources, including diesel and electric machines and heat exchangers. Strata heat loads are calculated within the program.
  
- o Fully Descriptive Output - At any desired interval along the airway, CLIMSIM (2.0) will list wet and dry bulb temperatures, moisture content, relative humidity, barometric pressure, density, air cooling power, enthalpy or sigma heat, virgin rock temperature or dry wall temperature, and effective temperature or wet bulb globe temperature.
  
- o Screen and Plotter Graphics - Each output parameter may be graphed against distance, both on the screen and on a multi-colored plotter.

- o Ease of Data Modification - Every individual input data item may be separately modified.
- o Complete Data File Management - Input data files can be saved under any name and on any drive, retrieved as input, listed, or deleted.

### 1.3 Hardware Requirements

CLIMSIM (2.0) was developed on an IBM PC/XT but is designed to operate on any IBM compatible micro-computer with a minimum of 256 k bytes of memory. CLIMSIM (2.0) may be run on a single or dual floppy drive system or on a fixed disk (hard disk) system.

For optimal performance of CLIMSIM (2.0), the following hardware is recommended:

- o Printer - An 80 (or greater) column printer should be available to help in keeping records of input and output data. This should be connected to the LPT1 parallel port.
- o Graphics Monitor and Card - Graphics output will be unavailable (even on a plotter) unless a monitor and graphics card compatible with the IBM Color/Graphics Adapter are available. A monochrome graphics monitor will usually also be acceptable.
- o Plotter - The CLIMSIM (2.0) graphics plotting routine is designed for a Hewlett Packard 7475A six pen plotter connected to one of the serial ports (COM1 or COM2). The plotter should be set to a 9600 baud rate, with other switch settings as follows:

Switch:	S2	S1	Y	US	A3	B4	B3	B2	B1
Setting:	0	0	0	*	*	1	0	1	0

\*Paper selection setting-see plotter manual.

Should the user have access to a micro-computer configured differently than suggested above, a customized version of CLIMSIM may be obtained.

## 2. STRUCTURE AND INPUT REQUIREMENTS

CLIMSIM (2.0) is an interactive, menu-driven program whose operation revolves around the Master Menu (Figure 2.1). After initial data input from the keyboard or from a saved data file, the Master Menu appears and offers the following options:

1. List input data on screen
2. List input data at printer
3. Execute program and list output on screen
4. Execute program and list output at printer
5. Proceed to data modification menu
6. Proceed to data file management menu
7. End CLIMSIM run

Options (1) and (2) list all input data on the monitor or printer, respectively, then return control to the Master Menu.

Options (3) and (4) execute the numerical climatic simulation procedure and list the results on the screen or printer, respectively. The user may then proceed, if desired, to a menu-controlled graphics routine which allows any output parameter to be plotted against distance on the screen and on the plotter.

Option (5) brings up the data modification menu which allows modification of individual data input items as well as the option to return to the initial data input section of the program.

Option (6) brings up the data file management menu which allows the user to save the current input data, read a previously saved data file, list the data file names, and delete data files.

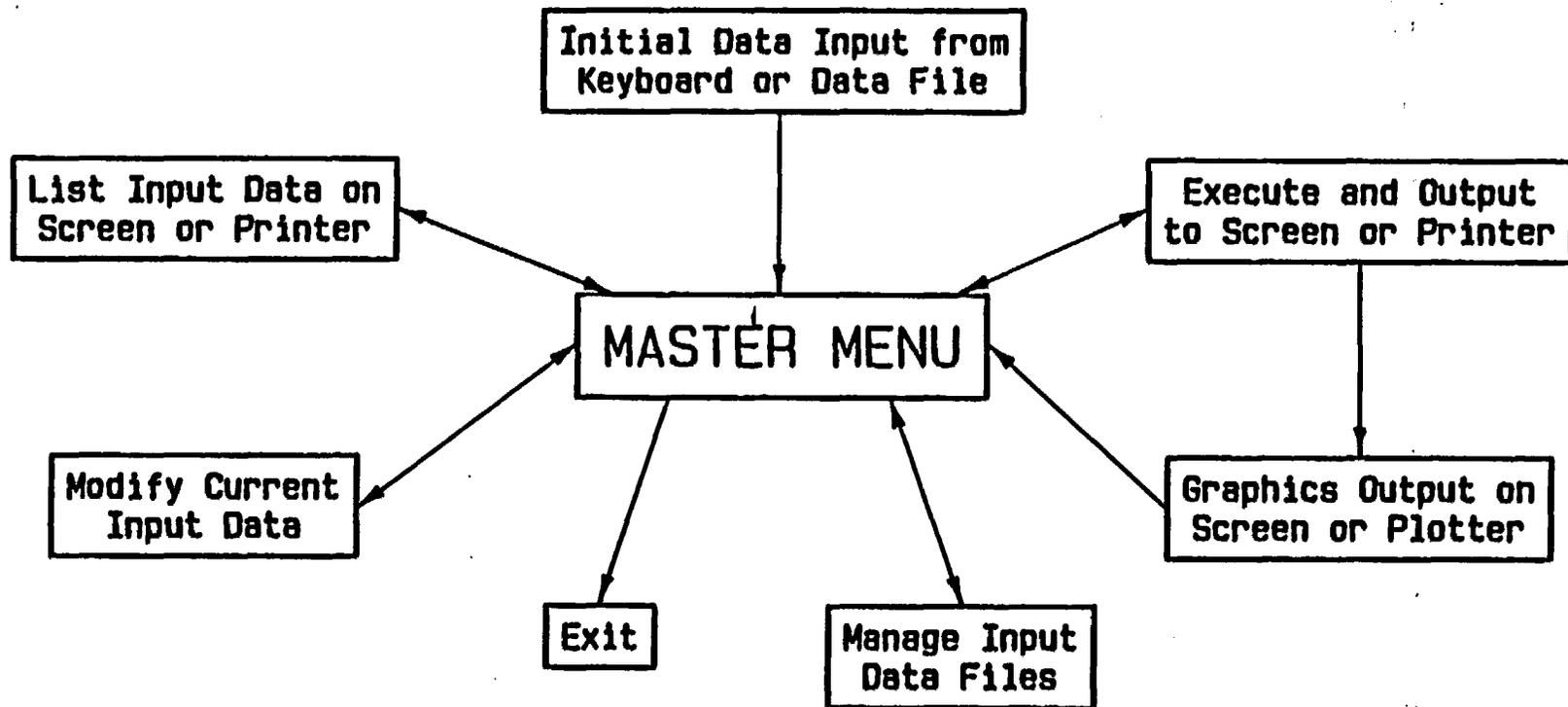


Figure 2.1: Structure of CLIMSIM

Option (7) ends the CLIMSIM (2.0) program session and returns control to the disk operating system (DOS). The current input data is not automatically saved when the program ends.

CLIMSIM (2.0) uses SI (International System) units. Hence, length is measured in meters, force in Newtons, mass in kilograms, power in Watts and work in Joules. Appendix I presents useful conversions between Imperial and SI units. A customized version of CLIMSIM (2.0) can be developed if Imperial rather than SI units are desired.

CLIMSIM (2.0) is designed to operate with a minimum amount of keyboard input. Nearly all single-character responses, such as menu item selections or Y/N answers, require only the appropriate key to be pressed. The Enter key should not be used for these inputs.

The rest of Section 2 describes in detail the options available in each section of the program and the required user inputs.

## 2.1 Initial Data Input

When the program is first entered and before the Master Menu can be accessed, data which controls the output operations and data describing the airway to be modeled must be supplied. The initial data input process is shown in Figure 2.2.

### 2.1.1 Configuration File (CONFIG)

The CONFIG file contains basic system configuration data required for a successful run on CLIMSIM (2.0). If the CONFIG file has not yet been created then the user is automatically prompted for input when CLIMSIM (2.0) first begins. This data is then saved in the CONFIG file and accessed for future program runs. If the CONFIG file already exists then the user may elect to either change the CONFIG file or proceed to the inputs of Section 2.1.2.

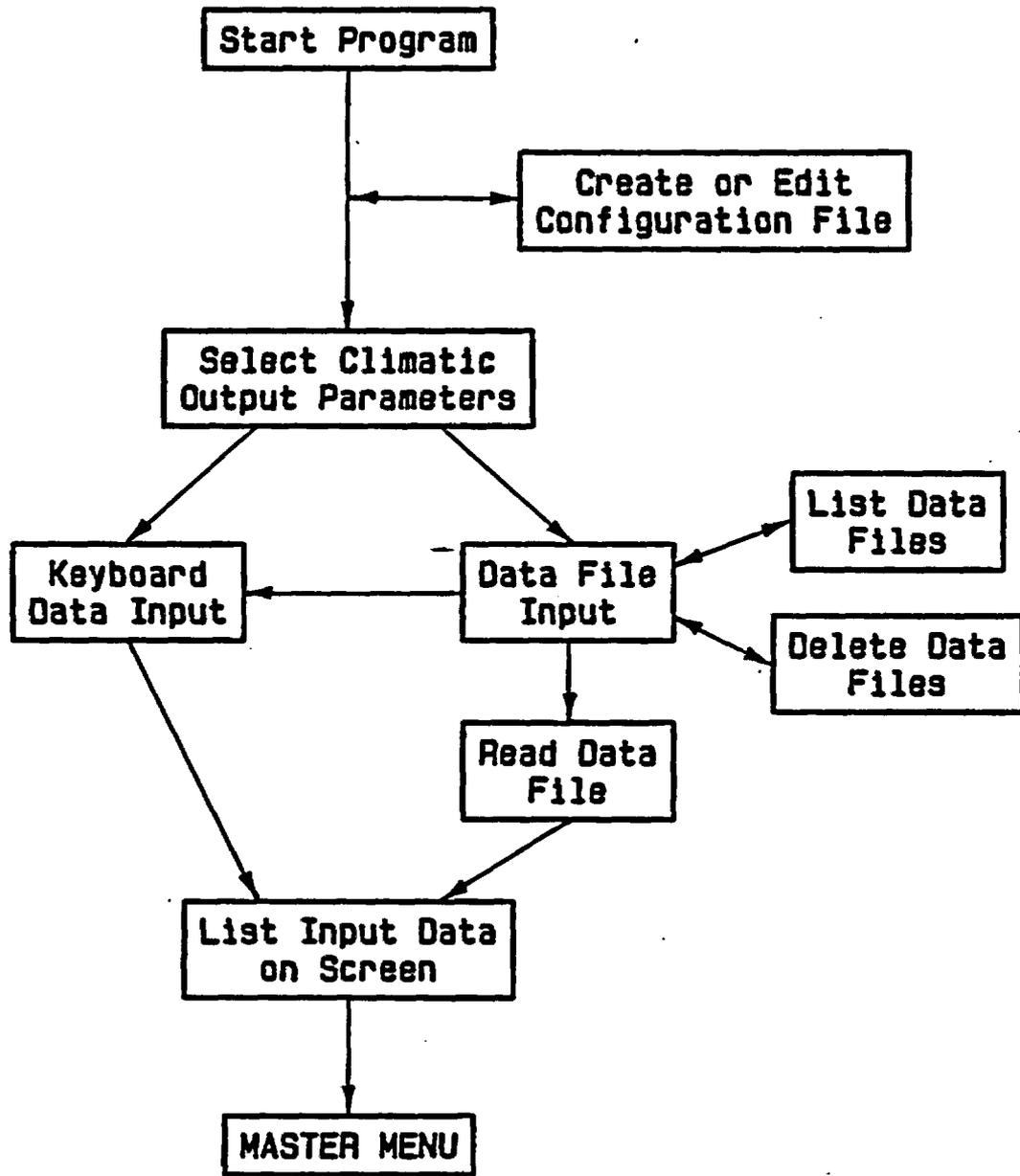


Figure 2.2: Initial Data Input

The first input required for the CONFIG file is the plotter connection, as follows:

- 0 - No Plotter
- 1 - Connected to COM1
- 2 - Connected to COM2

COM1 and COM2 are alternative communications ports to which the plotter may be connected. The user should ascertain which port is current on his hardware configuration. The user must press 0, 1, or 2. The Enter key is not required.

This input is followed by the question "Do you want a page header block on each page of output? (Enter Y or N)." If "Y" is depressed then the user is prompted to enter a title line. This input must be 40 characters or less, may include commas or other delimiters, and is ended by depressing the Enter key.

The format of the page header block, which will be printed at the top of each page of printer output (options (2) and (4) of the Master Menu), is shown below.

YOUR TITLE LINE HERE	CLIMSIM VERSION 2.0	FINAL FILING
		PAGE NO. _____
Job No. _____	Sheet ____ of ____	
Job Title _____	DESIGNED BY: _____	DATE _____
Description: _____	CHECKED BY : _____	DATE _____

---

### 2.1.2 Climatic Output Parameters

The user may tailor the output information by choosing which parameters will be listed in addition to dry and wet bulb temperatures, moisture content, relative humidity, pressure, density and air cooling power (ACP).

In addition to ACP, heat stress indices that may be listed are effective temperature (°C), wet bulb globe temperature (°C), both or neither. The heat content may be listed as enthalpy (kJ/kg) or sigma heat (kJ/kg). The rock

temperature may be listed as dry wall temperature ( $^{\circ}\text{C}$ ) or virgin rock temperature ( $^{\circ}\text{C}$ ). The user is prompted for each of these three choices, which require single key inputs only.

### 2.1.3 Input Data

Input data is the information required to describe the airway and its heat sources, and allow simulation of the climatic and psychrometric changes in the air as it travels along the airway. The user is prompted to declare whether this data will be entered from the keyboard or read from a pre-existing data file.

If data file input is chosen, the following menu appears.

1. List data files on drives
2. Read data file from drive
3. Delete data files
4. Input data from keyboard

The first three options are described in Section 2.6. The last option allows the user to enter the data from the keyboard instead of reading it from a file.

Once the data has been entered either from the keyboard or read from a file, it is listed on the screen to allow for checking of input values, then control is passed to the Master Menu.

The following subsections describe the input data required. All input data items must be followed by the Enter key. Depressing only the Enter key results in a numeric entry of zero.

#### 2.1.3.1 Description of airway

##### Name of branch

This identification of the airway should be 40 characters or less and cannot contain commas or quotation marks. If no entry is desired then depress only the Enter key.

Length to nearest meter

The airway length must be greater than 2 meters and not greater than 4,000 m.

Depth at intake end (m) and Depth at outlet end (m)

This refers to the depths of the two ends of the airway in meters below ground surface. Entries must be positive numbers. The intake end is the end at which the airflow enters.

Cross-sectional area (m<sup>2</sup>)

This is the average cross-sectional area of the entire airway.

Perimeter (m)

The average perimeter of the airway cross-section should be entered, allowing for irregularities of the surface. If a null or zero entry is made, then the airway cross-section is assumed to be a perfect circle.

Friction coefficient (kg/m<sup>3</sup>)

The friction coefficient, or friction factor, (k), is given in Atkinson's equation in the definition of resistance, i.e.,  $R = ks/A^3$ , where s is the internal rubbing surface of an airway and A is the cross-sectional area. Table 2.1 gives friction factors for various shapes and linings of shafts and roadways. The friction factor depends primarily on the roughness of the airway.

To convert friction factors from Imperial units to SI units they should be multiplied by  $1.8554 \times 10^{-4}$ . This assumes the Imperial friction factors are referred to pressure drops measured in lbf/ft<sup>2</sup>, air velocities in thousands of ft/min, and an air density of 0.075 lbf/ft<sup>3</sup>. For example, a smooth

concrete-lined unobstructed shaft would have a friction factor of about 16 in Imperial units.

**Table 2.1: Values of Airway Friction Coefficient  
(for air density = 1.2 kg/m<sup>3</sup>)**

<b>SHAFTS</b>	<b>kg/m<sup>3</sup></b>
Smooth concrete-lined unobstructed.....	0.0030
Brick-lined, unobstructed.....	0.0037
Smooth concrete-lined, with rope guides and pipe ranges on buntions.....	0.0065
Brick-lined, with rope guides and pipe ranges on buntions.....	0.0074
Tubbing-lined, with no guides or cages.....	0.0139
Timber-lined, no middle buntions.....	0.0167
Brick-lined, two lines of side buntions, without tie girders.....	0.0176
Brick-lined, two lines of side buntions, one tie girder to each buntion.....	0.0223
Timber-lined, with middle buntions.....	0.0223
<b><u>STEEL ARCHED ROADWAYS</u></b>	
Smooth concrete all round.....	0.0037
Concrete slabs or timber lagging between flanges all round.....	0.0074
Concrete slabs or timber lagging between flanges to spring.....	0.0093
Lagged behind arches, good condition.....	0.0111
Rough conditions with irregular roof, sides and floor.....	0.0158
<b><u>RECTANGULAR ROADWAYS</u></b>	
Smooth concrete-lined.....	0.0037
Girders on brick or concrete walls.....	0.0093
Unlined airways with uniform sides.....	0.0121
Unlined airways, irregular conditions.....	0.0158
Girders or bars on timber props.....	0.0186

### Wetness factor (dimensionless)

The wetness factor is defined as the fraction of airway surface that is wet. As an example, if 20% of the surface of an airway appears moist or wet, the wetness factor would be 0.2. In the majority of mines evaporation occurs even for apparently dry rock. The wetness factor will normally be in the range 0.04 (apparently dry) to 0.25. A null or zero entry will be accepted, but the program will internally use a value of 0.00001.

### Age at intake end (days) and at outlet end (days)

The age of a shaft or roadway is an important factor in determining the rate of the heat flow between the rock and the air stream. Heat flow from the rock to an airway is greater for a freshly exposed surface. The program computes the age of each section of the airway by interpolating linearly between the ages at the two ends. If desired, the average age of the entire airway may be input for both ends. This, however, is not recommended for young drivages. One age may be equal to zero, but not both.

#### 2.1.3.2 Ventilation conditions at intake

These parameters, which describe the air entering the airway, can be determined from measured data or from an earlier run of CLIMSIM (2.0) for the upstream airway(s).

### Quantity of airflow (m<sup>3</sup>/s)

Airflow must be a positive number and should not normally be higher than 1000 m<sup>3</sup>/s.

### Pressure (kPa)

The barometric pressure must lie between 75 and 300 kPa.

### Dry bulb temperature (°C) and Wet bulb temperature (°C)

Dry bulb temperature must lie between 0 and 120 °C. Wet bulb temperature must lie between 0 and 100 °C and must be less than or equal to the dry bulb temperature.

#### 2.1.3.3 Thermal parameters

This set of input parameters is concerned with the thermal conditions in the surrounding rock. Table 2.2 shows some typical values of rock thermal properties.

### Virgin rock temperature at inlet (°C)

The virgin rock temperature (the temperature of undisturbed rock) increases as the depth below the earth's surface increases. This change in temperature is a result of the flow of heat from the interior to the surface of the earth and is modified by local effects such as groundwater flow and geothermal anomalies or radioactive decay. Information on virgin rock temperatures is usually obtained either from measurements in boreholes drilled from surface or from measurements made in existing mines.

### Geothermal step (m/°C)

The geothermal step is the rate at which the virgin rock temperature varies with depth. It is the inverse of geothermal gradient (°C/m).

### Thermal conductivity (W/m/°C)

Thermal conductivity is a measure of the ability of the rock to conduct or transmit heat. The better the conductor, the higher the value of conductivity. This property can be determined experimentally. The input value must lie between 1 and 40. For rock, the normal range is from 1 to 8 W/m/°C.

Thermal diffusivity (m<sup>2</sup>/sec)

Thermal diffusivity is concerned with the rate at which the exposed rock cools and is defined by the relationship:

$$\text{Diffusivity} = \frac{\text{Conductivity}}{\text{Density} \times \text{Specific Heat}}$$

If diffusivity is unknown, enter zero. The program will then ask for:

- (i) Specific heat (J/kg/°C)
- (ii) Rock density (kg/m<sup>3</sup>)

The specific heat of the rock is defined as the amount of heat required to raise the temperature of a unit mass one degree. Both the rock density and specific heat can be determined experimentally.

Diffusivity values are of the order of 10<sup>-6</sup>, but the program internally adds the 10<sup>-6</sup> factor. A value of 9 x 10<sup>-7</sup> should be input as 0.9, for example. The value of diffusivity, either entered directly or calculated from specific heat and rock density inputs, must be in the range .006 x 10<sup>-6</sup> to 13.9 X 10<sup>-6</sup> m<sup>2</sup>/s.

Table 2.2: Typical Values of Thermal Properties

	Clays	Coal Measures	Limestone	Sandstone	Quartzite
Geothermal Step (m/°C)	24	30	46	50	120
Conductivity (W/m/°C)	1.8	2.2 - 3.0	3.3	3.6	6.0
Diffusivity (m <sup>2</sup> /s) x 10 <sup>-6</sup>	0.92	1.39	1.67	1.67	2.50

#### 2.1.3.4 Additional heat sources

The CLIMSIM (2.0) code handles heat exchange with the strata and the effects of autocompression of the air. There are, however, many other factors that cause climatic changes. These must be supplied on an individual basis by the user.

Machinery, heat exchangers, broken rock, and standing or flowing water all add or take heat from the air and directly influence the underground environment. CLIMSIM (2.0) divides heat sources into two categories, spot heat sources and linear heat sources, as described below. A maximum of 15 spot and 15 linear sources are allowed in any airway. Spot heat sources must be designated as non-machine or machine.

In general, heat energy may be transferred to the air in the form of sensible heat, latent heat or a combination of the two. If the heat source involves neither evaporation nor condensation of water and there is no chemical formation or absorption of water vapor, then the transfer will consist entirely of sensible heat. Examples are electrical equipment or any hot dry surfaces. The addition (or subtraction) of sensible heat causes changes in both the dry bulb and wet bulb temperatures of the air but the moisture content remains constant.

Latent heat addition occurs when the heat energy is used to excite water molecules to the extent that their kinetic energy increases sufficiently for them to escape from the liquid surface and become airborne molecules of water vapor. If this process of evaporation occurs without the simultaneous transfer of sensible heat, i.e. if the liquid surface is at dry bulb temperature, then the wet bulb temperature and moisture content will increase but the dry bulb temperature will remain constant. However, in most cases, latent heat exchange is accompanied by sensible heat transfer. Condensation is the reverse of evaporation and results in a reduction in moisture content of the air. Sensible heat and latent heat transfers may occur in opposite directions at a liquid

surface if that surface has a temperature less than that of the dry bulb temperature of the airstream. In particular, if the liquid surface is at wet bulb temperature then an adiabatic saturation process occurs when the sensible heat loss from the air to the water is balanced precisely by the latent heat transfer from the water to the air. In this situation, the dry bulb temperature of the air will fall, but its wet bulb temperature will remain constant.

The evaporation or condensation (and hence, latent heat transfers) that occur on the rock surfaces of an airway are handled automatically by CLIMSIM (2.0). However, artificial sources of heat or cooling are so varied and site-dependent that their division into sensible and latent heat components are left largely to the user's discretion. A major exception is the case of internal combustion engines in which a proportion of the fuel energy is utilized in producing water vapor in the combustion process, in exhaust scrubbers and in machine cooling devices. The widespread use of diesels in mining has prompted the incorporation of these latent and sensible heat calculations within the CLIMSIM (2.0) code.

#### Non-machine spot heat sources

This category is used for any stationary non-machine source of heat or cooling concentrated at one specific site, such as a heat exchanger, muck pile or water pond. For each source the user must input the location as distance from the intake end (m), the sensible heat load (kW), and the latent heat load (kW).

#### Machine spot heat sources

This category applies to machinery that moves only a short distance or spends all or most of its time at one location, such as a transformer, conveyor gearhead, crusher, mucker, shuttle car or LHD. For each piece of equipment the

user must input distance from intake (m), full load power output (kW), percent utilization at equivalent full load, and whether it is diesel or electric. A diesel machine requires an additional entry for the liters of water emitted per liter of fuel consumed. The latter is normally in the range 3 to 10 liters/liter, depending upon the design of the diesel, method of engine cooling, exhaust emission control devices, and the quality of maintenance.

The full load power output multiplied by the percent utilization should give the average power output for a shift, accounting for periods of non-operation and periods of operation at less than full load.

For an electric machine, the program applies 100% of the average power output to a sensible heat load. Electric machines are assumed to be 100% efficient, so the user should enter a value for full load power output that reflects the actual power consumed at full power operation.

Total diesel heat is computed as 2.83 times the average power output. This reflects the efficiency of a diesel engine and assumes that 0.3 liters of fuel are consumed for each kW of power output per hour<sup>1</sup>. Latent heat is calculated from water emission and average power output, using the same assumption. Sensible heat load is total diesel heat minus latent heat load.

### Linear heat sources

Linear heat sources are sources of heat or cooling that act over a considerable distance, such as a conveyor belt, uncovered water channels, ducts and pipes, or a machine that spends most of its time travelling along the airway. The required inputs for each source are the position of the beginning of the source (m) measured from the intake end, length of source.

1. McPherson, M.J. (1984) Mine Ventilation Planning in the 1980's. International Journal of Mining Engineering, 2, 185-227.

in the direction toward the outlet end (m), sensible heat load (kW), and latent heat load (kW).

Electric equipment can be input by applying all the average power output toward sensible heat. Diesel equipment can only be included as a linear source if both sensible heat load and latent heat load are first calculated.

#### 2.1.3.5 Distance between temperature outputs (m)

This determines the number of output stations for the calculation results and also affects the length increment used by the program calculation routine. The requested distance between outputs is adjusted to cover the full airway length with an integral number of evenly spaced output stations. The number of output stations must not exceed 200. The distance between outputs cannot be less than 2 meters.

If the distance between outputs is less than 20 m, then this distance is used for the internal calculation increment. If it is greater than 20 m then it is divided into an integral number of equal calculation increments, all less than or equal to 20 m.

## 2.2 List Input Data

Options (1) and (2) of the Master Menu list the input data on the screen and printer, respectively. If the CONFIG file was set up to include a page header block for printer output, then this header will appear at the top of each page.

All input data described in Section 2.1.3 are listed. The number of output stations is computed and listed together with the requested distance between outputs.

Listed with the rock thermal parameters is the overall heat transfer coefficient, which is a measure of the efficiency with which the strata heat passes from the rock surface, through the air boundary layers, to the main airstream. The heat transfer coefficient,  $h$ , depends mainly on the airway friction factor,  $k$ , and the mean air velocity,  $u$ . It is calculated by CLIMSIM (2.0) using the following empirical equation<sup>2</sup>.

$$h(\text{W/m}^2/\text{°C}) = 3476 (\text{m}^2/\text{s}^2/\text{°C}) * \underline{k}(\text{kg/m}^3) * u(\text{m/s})$$

2. Scott, D.R. (1958), The Cooling of Underground Galleries. Transactions of the Institution of Mining Engineers, U.K., 118, 356-372.

### 2.3 Execution and Output

Options (3) and (4) of the Master Menu will execute the numerical climatic simulation procedure and list results on the screen or printer, respectively. If the CONFIG file was set up to include a page header block for printer output, then this header will appear at the top of each page. CLIMSIM (2.0) runs very rapidly on modern microcomputers and the results appear within seconds following the initiation of an execution run.

For each output station the program will list the distance from intake end (m), dry bulb temperature ( $^{\circ}\text{C}$ ), wet bulb temperature ( $^{\circ}\text{C}$ ), moisture content (g/kg), relative humidity (%), barometric pressure (kPa), air density ( $\text{kg}/\text{m}^3$ ), air cooling power ( $\text{W}/\text{m}^2$ ), plus the additional climatic output parameters selected at program initiation (Section 2.1.2). If virgin rock temperature was not selected as an output parameter, the final VRT at the outlet end is listed at the bottom of the output.

The positions of heat sources are indicated by listing each heat source between the appropriate two output stations. The program outputs the heat source type (spot or linear), source number, sensible heat load, latent heat load, and, for linear sources, the heat source length.

If the wet bulb temperature at any point along the airway exceeds the wall rock temperature then this indicates that condensation will take place. If this occurs then the message "XXm along airway \*\*\*\*\* condensation started \*\*\*\*\*" will appear between the appropriate two output stations. Such condensation will occur on all surfaces with a temperature below that of the air wet bulb temperature, and perhaps also as a fog within the airstream. When this condition no longer holds the program will also list the position of this occurrence as "XXm along airway \*\*\*\*\* condensation terminated \*\*\*\*\*".

After the output to the screen or printer is completed, the user has the opportunity of proceeding with graphics output, which is described in Section 2.4. If graphics are not desired, or if graphics capability is unavailable, control returns to the Master Menu.

## 2.4 Graphics Output

After viewing the climatic simulation results on the screen or printer (options (3) and (4) of the Master Menu) the user may elect to view the results graphically. This option is not available unless the screen has graphics capability, and hard copy plotting is not possible unless an appropriate plotter is connected (see Section 1.3).

### 2.4.1 Graphics Menu

If graphics output is chosen, the user is presented with a menu of all output parameters, any of which may be plotted against distance. The menu consists of an 8 parameter selection; selection (9) returns control to the Master Menu. If air cooling power was the only heat stress index chosen during the inputs of section 2.1.2 then selection (8) will be "Air cooling power." If effective temperature or wet bulb globe temperature was also requested then selection (8) will be "Heat stress indices". In this case pressing "8" will bring up a small menu from which the desired heat stress index can be chosen.

After the chosen parameter has been plotted on the screen, the user must press the Enter key to clear the screen and proceed. This instruction appears before the graph is made but not with the graph. This allows the graph to be sent to the printer with the PrtSc key if desired (this requires that the DOS GRAPHICS command be executed prior to beginning CLIMSIM (2.0)). After the Enter key has been pressed, the following options are available.

1. Redraw graph to your axes
2. Plot graph on plotter
3. Return to graphics menu

The first two options are described in the next two subsections. The third option allows the user to plot a different parameter on the screen or return to the Master Menu.

#### 2.4.2 Redraw Graph to Own Axes

This option allows the user to change the default axis ranges. The user is prompted to enter the maximum value for the X axis (distance), the minimum for the Y axis, and the maximum for the Y axis. The X axis minimum is fixed at zero. The three values should be separated by commas and the Enter key depressed after all three have been typed in. If the message "Redo from start" appears then all three must be re-entered.

The graph will be redrawn with the new axes, and will remain on the screen until the Enter key is depressed. After viewing the graph the user may choose to either redraw it again, plot it as is on the plotter, or return to the graphics menu.

#### 2.4.3 Plot Graph on Plotter

This option will plot the previously viewed graph on the plotter, utilizing the multiple pen capabilities. The plot functions will be listed on the screen for the different pens, along with the instruction to "set-up plotter and press return when ready".

Before the Enter key (return) is pressed, the plotter must be turned on, properly connected, and loaded with paper. If, at this point, a plot is not desired, the user may press the Enter key with the plotter turned off to abort the plotting process. Once the plotting has begun, it may be aborted by pressing the F1 key. If the F1 key is pressed the plotter buffer will empty, after which the Enter key can be pressed to continue with the program.

After the plotting routine is either successfully completed or aborted, the user may again choose to redraw the graph, plot it on the plotter, or return to the graphics menu.

## 2.5 Data Modification

Selection of option (5) from the Master Menu allows the user to modify the current input data. These operations are controlled by the data modification menu, which divides the input data into six different groups to facilitate modification choices. The following options are available (see Figure 2.3):

1. Description of airway
2. Inlet conditions to airway
3. Rock thermal parameters
4. Spot heat sources
5. Linear heat sources
6. Distance between outputs (xx m)
7. Re-enter data from the beginning
8. Continue to Master Menu

Options (1) through (7) are described in the following subsections.

### 2.5.1 Description of Airway

The current airway descriptive data are listed on the screen in menu form:

1. Length (xx m)
2. Depth at inlet (xx m) and outlet (xx m)
3. Cross-sectional area (xx m<sup>2</sup>)
4. Perimeter (xx m)
5. Friction factor (xx kg/m<sup>3</sup>)
6. Wetness factor (xx dimensionless)
7. Model name (nnnn)
8. Age at inlet (xx days), at outlet (xx days)
9. Return to modification menu

These data are altered by depressing the appropriate number, which allows the user to input a new value. After each change the data list is updated.

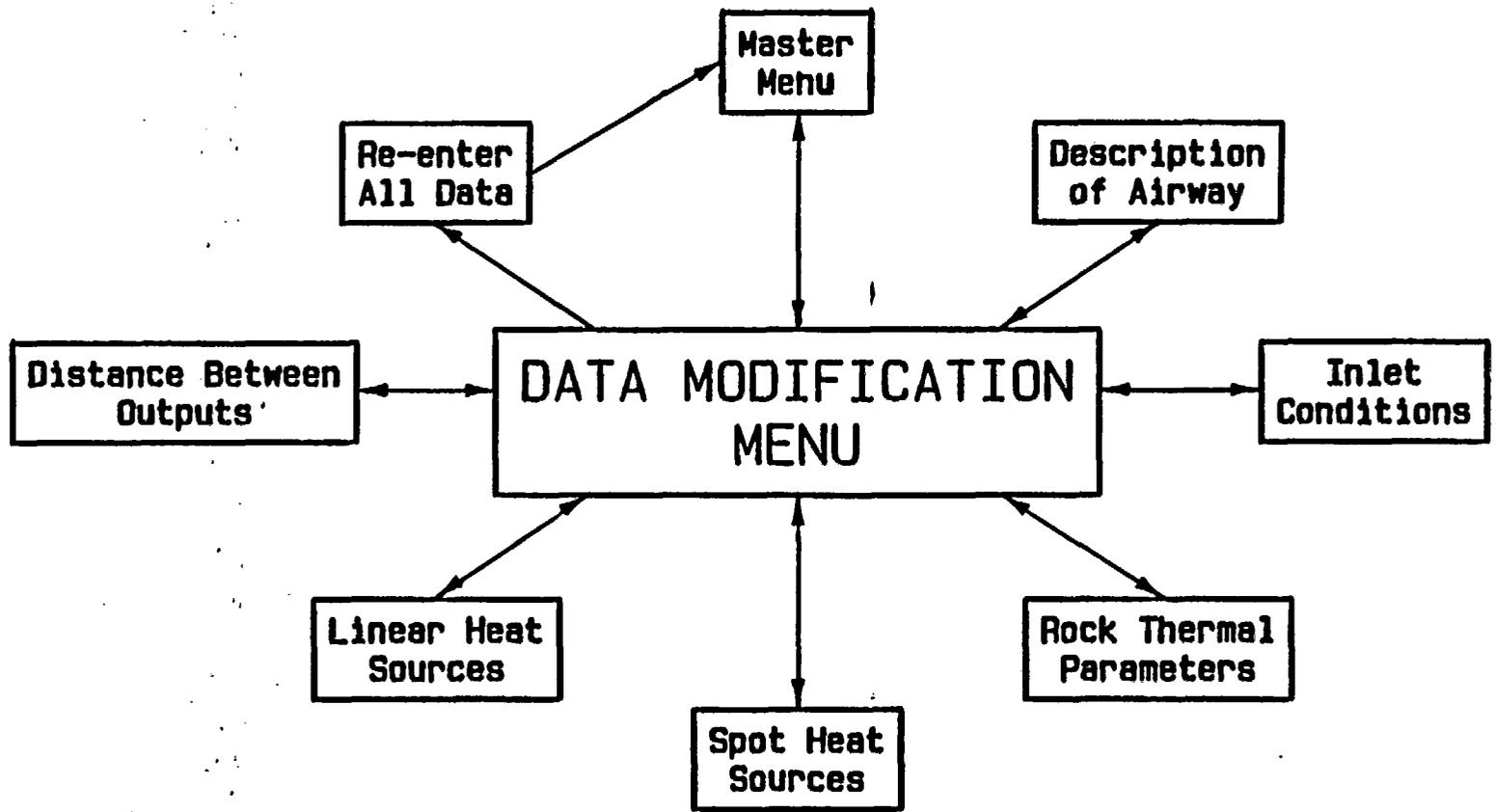


Figure 2.3: Data Modification

Explanations of these data inputs and their restrictions can be found in Section

2.1.3.1. The combination of the new length and the existing distance between outputs must not result in more than 200 output stations.

#### 2.5.2 Inlet Conditions to Airway

The current airway inlet conditions are listed on the screen in menu form:

1. Inlet airflow (xx m<sup>3</sup>/s)
2. Inlet pressure (xx kPa)
3. Inlet dry bulb temperature (xx C)
4. Inlet wet bulb temperature (xx C)
5. Return to modification menu

These data are altered by depressing the appropriate number, which allows the user to input a new value. The data list is updated after each input.

These data items and their restrictions are described in Section 2.1.3.2.

#### 2.5.3 Rock Thermal Parameters

The current rock thermal parameters are listed on the screen in menu form:

1. Inlet VRT (xx C)
2. Geothermal step (xx m/C)
3. Conductivity (xx W/m/C)
4. Diffusivity (xx m<sup>2</sup>/sec)
5. Return to modification menu

These data are altered by depressing the appropriate number, which allows a new value to be input. The data list is updated following each new input.

Descriptions of these inputs and their restrictions can be found in Section 2.1.3.3.

Unlike the initial data input routine, specific heat and rock density cannot be input in lieu of diffusivity. A value for diffusivity must be known.

#### 2.5.4 Spot and Linear Heat Sources

Selection of either of these modification options will bring up a menu of the following form, which will pertain to either spot sources or linear sources, as appropriate.

1. View heat source data
2. Re-enter a single heat source
3. Delete a heat source
4. Add a heat source
5. Re-enter all spot (linear) heat sources
6. Return to modification menu

The actions of these options are described below. Every option acts only on spot sources or only on linear sources, depending upon which choice was made from the data modification menu.

##### View heat source data

This option will list on the screen the current spot (linear) heat source input data.

##### Re-enter a single heat source

This option will list the current heat source data and ask the user to enter the number of the heat source to be modified. The user may escape by entering zero or any other invalid heat source number. Following the input of a valid source number, the screen will clear and request input of the new information, in the same manner as described in Section 2.1.3.4. After the heat source has been modified, all spot (linear) sources will be listed.

##### Delete a heat source

This option will list the current heat source data and ask the user to enter

the number of the heat source to be deleted. The user may escape by entering zero or any other invalid heat source number. Following input of a valid heat source number, the source will be deleted and the heat sources will be renumbered accordingly and listed on the screen.

#### Add a heat source

When adding a heat source, a source number is automatically assigned and the program will request input of the required information, as described in Section 2.1.3.4. When modifying linear sources, the new source is appended to the end of the existing linear sources. Because spot sources are divided into non-machine and machine, and non-machine are always listed first, the program will ask whether the new source is non-machine or machine. If it is a machine source then it is appended to the end of the existing spot sources. If it is a non-machine source then it is inserted immediately before the first machine source and all the machine sources are renumbered accordingly. When adding sources the user must remember that no more than 15 spot and 15 linear sources are allowed.

#### Re-enter all spot (linear) heat sources

This option deletes all current spot (linear) heat sources and allows the user to re-enter as many as desired (up to 15). The program first asks for the number of sources (both non-machine and machine for spot sources) to be entered and then requests input in the same manner as described in Section 2.1.3.4.

#### 2.5.5 Distance Between Outputs

The data modification menu lists the current user-requested distance between outputs as option (6). The value is changed by pressing "6" and then responding to the prompt for a new value. The significance of this parameter is described

in Section 2.1.3.5. When modifying both length and distance between outputs, the user must remember that at no time will the program allow the number of output stations to exceed 200.

#### 2.5.6 Re-enter Data From Beginning

This option allows all data, including climatic output parameter choices, to be re-entered. Selecting this option sends the user back to the point of initial data input described by Section 2.1.2 (see Figure 2.2). After choosing desired climatic output parameters the user may elect to enter the new input data from the keyboard (Section 2.1.3) or read the data from a file. If file input is chosen then control passes to the data file management menu (Section 2.6) and the current input data is not replaced until a new data file is read.

If it is desired to replace the current input data with data from a file, but leave the climatic output parameters unchanged, it is much quicker to go directly to the data file management menu from the Master Menu, rather than selecting option (7) of the data modification menu. It is also important to remember that the current input data is never saved unless explicitly done so through option (4) of the data file management menu (Section 2.6.4).

#### 2.6. Data File Management

Selection of option (6) brings up the data file management menu, which allows the following options (Figure 2.4).

1. List data files on drives
2. Read data file from drive
3. Delete data files
4. Save current input data
5. Continue to Master Menu

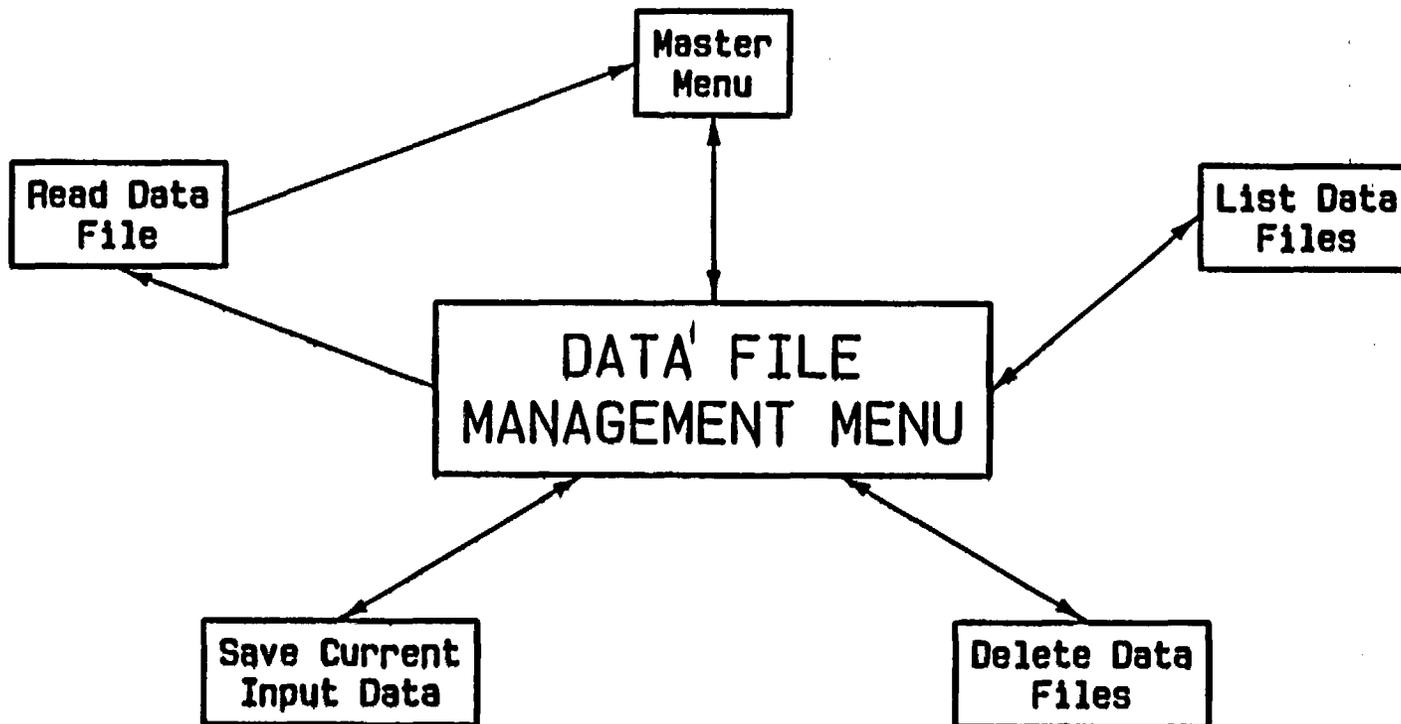


Figure 2.4: Data File Management

### 2.6.1 List Data Files on Drives

Selection of this option prompts the question "Input drive A, B, or C". Depending on the configuration of the system the user enters a disk drive from which the input data files are to be listed. Entries do not require capitalization. Should an incorrect letter be entered, the user is prompted to re-enter. The screen will then list the names of all input data files currently available on the drive.

### 2.6.2 Read Data File From Drive

This option allows a stored data file to be read from a disk drive and become the current input data. The new data will replace the existing input data, which is not automatically saved.

The user is prompted to enter the file name and the drive on which the file exists. If the data file was stored on a floppy diskette, it must be placed in the drive unit and the appropriate drive letter selected. After the file is read in, the input data is listed on the screen and control returns to the Master Menu.

### 2.6.3 Delete Data Files

This option allows input data files to be deleted from a floppy diskette or fixed disk. The user is prompted to enter the drive label A, B or C, for the drive from which the files are to be deleted, the number of files to be deleted (up to 10) and the individual file names. A list of existing files should be obtained to facilitate the deletion process. All entries are scrutinized by the program; should they be invalid, their re-entry is prompted.

### 2.6.4 Save Current Input Data

The option to save the input data is made available only after the data has

been input from the keyboard or from a data file. A data file that has been read in and altered can be re-named, or the old file overwritten, upon user discretion.

If the current input data was entered from the keyboard, the user is prompted to enter a file name. The file name cannot be longer than seven characters and cannot contain colons or decimal points. Characters can be entered in upper or lower case.

After a file name has been entered, or if the data was read from disk and already has a file name, the current file name is listed and an opportunity given to change the file name. If extensive modifications have been conducted on a pre-existing file and it is desired that the original file remain intact, a new file name should be entered. If the original file name is maintained, the user is notified that the file already exists and that it will be overwritten. The user may opt not to overwrite the file at this point and is prompted to enter a new file name. Files may be saved on hard disk or floppy diskette by specifying the appropriate drive letter A, B, or C. Capitalized entries are not required.

### 3. INSTALLATION AND FILE MANAGEMENT

This section first describes the installation procedure which must be followed in order to commission CLIMSIM (2.0). Second, a file management procedure is suggested. This entire section should be read before any hands-on use of CLIMSIM (2.0) is attempted. In particular, Section 3.1.2.3 must be studied and understood before attempting to install the program on a hard disk.

#### 3.1 Installation

CLIMSIM (2.0) may be run directly from a floppy drive or may be installed on, and run from, a fixed disk drive (hard disk). If your system has a fixed disk you have the option of using only the floppy drive (Section 3.1.1), but it is highly recommended that CLIMSIM (2.0) be installed on the fixed disk (Section 3.1.2). There are two reasons for this. First, read and write operations to program and data files are much faster. Second, CLIMSIM (2.0) operates on the CONFIG file, which resides on the same directory as the CLIMSIM (2.0) program files, every time the program is run. Constant reading and writing to the original diskette will reduce its life.

Whichever procedure you choose, be sure to read Section 3.1.3, which discusses backup and care of the CLIMSIM (2.0) diskette.

##### 3.1.1 Floppy Drive System

CLIMSIM (2.0) does not actually need to be installed on the hard disk in order to run it direct from a floppy drive. Each time you wish to run CLIMSIM (2.0), the original CLIMSIM (2.0) diskette should first be placed in the default drive. Entering the command "CLIMSIM" will begin the program, which makes use of the CLIMSIM.EXE file and the SETUP.EXE file. The HDUTIL.EXE file is not required, but it should be left on the diskette.

The SETUP.EXE file never needs to be run separately. It is called

automatically by CLIMSIM (2.0) to allow creation and alteration of the CONFIG file (Section 2.1.1), which is stored along with the two program files.

To prevent unauthorized duplication, CLIMSIM (2.0) is linked to a unique key on the original CLIMSIM (2.0) diskette. This key must be accessible to CLIMSIM (2.0) each time it is run. Therefore, if you have only a single floppy drive, CLIMSIM (2.0) cannot be run from a backup copy; the original diskette must always be used. Once you have reached the Climatic Output Parameter inputs (Section 2.1.2), however, the CLIMSIM (2.0) diskette may be removed to allow a separate data file diskette to be accessed (Section 3.2).

If you have dual floppy drives, the following procedure is recommended to allow key access but prevent excessive use of the original CLIMSIM (2.0) diskette. Make two identical backup diskettes as described in Section 3.1.3., one of which will be used as a run-time diskette. The only files required on the run-time backup diskette are CLIMSIM.EXE and SETUP.EXE. Place this diskette in the default drive each time you wish to run CLIMSIM (2.0), and place the original CLIMSIM (2.0) diskette in the second drive. CLIMSIM (2.0) will find the key on the second drive and allow the program to run, while storing the CONFIG file on the run-time backup diskette in the default drive. Once you have reached the Climatic Output Parameter inputs (Section 2.1.2), the original CLIMSIM (2.0) diskette may be removed from the second drive. If CLIMSIM (2.0) cannot find the key, the message "Please insert key diskette and try again" will appear and control will return to DOS.

### 3.1.2 Fixed Disk System

The following steps should be followed to install CLIMSIM (2.0) on a fixed disk. This procedure copies all files from the CLIMSIM (2.0) diskette into a sub-directory on your fixed disk.

### 3.1.2.1 Set up sub-directory

From your main directory, create a sub-directory with the DOS command "MKDIR". Specify the sub-directory name or a path and sub-directory name. For example, from the main directory enter:

```
MKDIR CLIM
```

This creates a sub-directory, CLIM, which branches from the main directory.

To move from the main directory to the CLIM sub-directory simply enter CD CLIM. Entering DIR lists the catalogue of files in CLIM which should initially be empty. To return to the main directory enter CD\.

### 3.1.2.2 Copying CLIMSIM (2.0) files to your sub-directory

Move to your newly created sub-directory, for example CLIM, by using the "CD" command. Determine the drive designation letter of your floppy diskette drive unit; it will normally be "A". Place the CLIMSIM (2.0) diskette in the drive unit and close the drive door. With "C" as the default drive, enter the following two DOS commands, assuming your diskette drive designation letter is "A":

```
COPY A:CLIMSIM.EXE
```

```
COPY A:SETUP.EXE
```

This copies the two CLIMSIM (2.0) files from the original diskette onto the sub-directory which from the "COPY" command was issued. Issuing a "DIR" command lists the CLIMSIM (2.0) program files in the sub-directory. Both CLIMSIM.EXE and SETUP.EXE should then reside in the sub-directory.

The program file HDUTIL.EXE should not be kept on the sub-directory as it is only used for the key installation option described in the next section.

After ensuring key availability, the program may be run by entering the command "CLIMSIM" while in the sub-directory. The SETUP.EXE file never needs to be run separately. It is called automatically by CLIMSIM (2.0) to allow

creation or alteration of the CONFIG file (Section 2.1.1), which is stored in the sub-directory along with the two program files.

### 3.1.2.3 Supplying the key - the install option

The CLIMSIM (2.0) program files are protected to prevent unauthorized duplication. To accomplish this, CLIMSIM (2.0) is linked to the unique key on the original CLIMSIM (2.0) diskette. This key must be accessible to CLIMSIM (2.0) for it to run properly. There are two ways to provide key access during runtime:

Option 1: Use the key on the CLIMSIM (2.0) diskette. You should choose this option if you are only temporarily locating CLIMSIM (2.0) on the specific hard disk. After copying the files over as described in Section 3.1.2.2, CLIMSIM (2.0) is ready to run. However, when beginning the program, and until you have reached the Climatic Output Parameter inputs (Section 2.1.2), the original CLIMSIM (2.0) diskette must be in the floppy drive with the drive door closed. If it is not, the message "Please insert key diskette and try again" will appear and control will return to DOS. If this happens, insert the CLIMSIM (2.0) diskette, close the drive door and re-enter the command "CLIMSIM".

Option 2: Install the key on the hard disk. You should choose this option if you plan to locate CLIMSIM (2.0) permanently on that specific hard disk. You may install the key four times, on different hard disks or on the same hard disk. However, the key must be uninstalled from its current location before it can be reinstalled on the same hard disk or on any other hard disk. Thus, the key can be installed on only one hard disk at a time. Uninstalling does not change the number of remaining installs; each install uses one of the four available installs. If all installs become used, contact Mine Ventilation Services for a new CLIMSIM (2.0) diskette.

The key may be installed before or after copying the program files to the

hard disk. To install the key, insert the CLIMSIM (2.0) diskette in the floppy drive and change the default drive letter to the floppy drive designation (normally A:). Enter the command "HDUTIL" which will start the Hard Disk Utility Program. From the menu that appears, choose the (Install Hard Disk) option and follow the instructions that appear on the screen. When key installation is complete, the CLIMSIM (2.0) diskette may be removed and stored permanently. From then on, it will not then be required during CLIMSIM (2.0) runtime.

To uninstall the key, you must again insert the CLIMSIM (2.0) diskette in the floppy drive, change the default drive to A:, and enter the command "HDUTIL". From the menu, choose the uninstall option. Do not uninstall unless you wish to permanently move CLIMSIM (2.0) to a different hard disk. The CLIMSIM (2.0) programs may be temporarily run on a different hard disk by copying them to that disk, as in Section-3.1.2.2, and running them as in option 1 of this section. You do not need to uninstall to do this.

If you wish to reformat your hard disk, and you have installed the key on it, be sure to uninstall the key before you reformat the hard disk. If you do not, you will not be able to reinstall the key. If this situation occurs accidentally, and you cannot reinstall the key, contact Mine Ventilation Services for a replacement CLIMSIM (2.0) diskette.

### 3.1.3 Backup and Care of the CLIMSIM (2.0) Diskette

It is recommended that you save backup copies of all the CLIMSIM (2.0) program files on an additional floppy diskette. When transferring files from the CLIMSIM (2.0) diskette use the DOS "COPY" command only. Do not use the "DISKCOPY" command.

If you accidentally erase a program file from the hard disk, it may be restored either from the original diskette or from your backup diskette. If you

erase a program file from the original diskette, it may be restored from the backup diskette or from the hard disk.

The backup program files are executable, but only if the key is available to them, just as with the original program files. The key exists only on the original CLIMSIM (2.0) diskette, or on a hard disk on which it has been installed from the original CLIMSIM (2.0) diskette. The key cannot be installed from the backup CLIMSIM (2.0) diskette. The HDUTIL program should only be executed from the original CLIMSIM (2.0) diskette; never from a backup diskette and never from the hard disk.

Never use the "FORMAT" command on the original CLIMSIM (2.0) diskette. If you are running CLIMSIM (2.0) under option 1 of Section 3.1.2.3, or are running CLIMSIM (2.0) directly from a floppy drive as in Section 3.1.1, do not place a write-protect tab on the CLIMSIM (2.0) diskette. Also, when executing the HDUTIL program, be sure there is no write-protect tab on the CLIMSIM (2.0) diskette.

Should you have any operational problems with the programs or diskette contact Mine Ventilation Services. We will be happy to assist you and will gladly replace the diskette if required.

### 3.2 File Management

This section suggests the file management procedure for both a floppy drive system and a fixed disk system.

With a single floppy drive system the two CLIMSIM (2.0) program files, as well as the CONFIG file that is created by CLIMSIM (2.0), all reside on the original diskette. This diskette may be removed from the drive, however, once CLIMSIM (2.0) has been loaded into memory and initialized. In this way a separate diskette may be used for data file storage, as is recommended.

With a dual floppy drive system the run-time backup diskette holds the two

program files and the CONFIG file, while the original CLIMSIM (2.0) diskette supplies the key. Both these diskettes may be removed, if desired, after CLIMSIM (2.0) has been loaded and initialized. Data files can be stored either on the run-time backup diskette or on a separate diskette. The desired storage drive is selected before saving the data (Section 2.6.4).

With a fixed disk drive, the CLIMSIM (2.0) program files and the CONFIG file are stored in a sub-directory while the input data files can be optionally stored in the sub-directory or on a floppy diskette. The storage drive designation is selected before saving the files (Section 2.6.4). If the original diskette is required for the key (option 1 of Section 3.1.2.3), it may be removed once CLIMSIM (2.0) is loaded and initialized.

It is recommended that you do not store data files on the original CLIMSIM (2.0) diskette. To view files on any diskette, assuming the diskette drive letter is "A", an "A:DIR" command may be issued while in DOS. This is not usually required, however, since normal operation of CLIMSIM (2.0) makes searching routines available for input data files (Section 2.6.1).

Data files may be transferred to other floppy diskettes or sub-directories by use of the DOS "COPY" command. For instance, if the CLIMSIM (2.0) program sub-directory on the fixed disk is heavily cluttered with data files from old analyses, the data can be transferred to a storage sub-directory or storage floppy. Consult your DOS manual for the specific command format required.

#### 4. PROGRAM OPERATION AND USE

This section describes the general procedure that should be followed in order to conduct a successful climatic simulation exercise with CLIMSIM (2.0). Before attempting a CLIMSIM (2.0) session with your own data or with the example given in Section 5, the CLIMSIM (2.0) program files and the key must be made available as explained in Section 3.1.

CLIMSIM (2.0) is an interactive menu-driven program, and as such the user responses and inputs are not described in detail in this section. Section 2 explains in detail the options and input requirements for each menu.

Before you begin the program, you must have available all the required input data for the airway (Section 2.1.2). The airway to be modeled must be a single airway with a single stream of air (no mixing). The climatic conditions of the air entering the airway may be determined either by direct measurement or by prior CLIMSIM (2.0) runs for the upstream airway(s). The inlet airflow rate may be an actual measured value, or it may be an intended future value determined by a ventilation network modeling program. Sources of heat or cooling may likewise represent either a present or future situation. When using CLIMSIM (2.0) to model future activities, it is of utmost importance to first correlate the present situation with a CLIMSIM (2.0) model. Section 4.4 discusses in detail the determination of uncertain input parameters and proper correlation techniques.

##### 4.1 Initial Data Entry

To begin CLIMSIM (2.0), change the default drive and directory, if appropriate, to allow access to the program files, and enter the command "CLIMSIM". If the CONFIG file has not yet been created, you will be prompted for the required input (Section 2.1.1). Throughout the program run, nearly all single-character responses, such as menu item selections or Y/N answers, do not

require the Enter (Return) key to be pressed. Press only the one key required.

After the CONFIG file has been created, you will be prompted to choose certain climatic output parameters (Section 2.1.2). If you are using the original CLIMSIM (2.0) diskette to supply the key, you may, at this point, remove the diskette if desired.

In response to the prompt, choose keyboard input as the source of input data. Enter each item as requested (Section 2.1.3), following every entry with the Enter key. Pressing only the Enter key returns a value of zero. If an incorrect entry is made, make a note of the error and proceed with data entry. Each data entry may be revised later as desired.

After the last data entry (distance between outputs) has been made, all input data will be listed on the screen. Check the input data carefully and note any input errors. Following the screen listing, the Master Menu will appear. The Master Menu controls all program operations (Figure 2.1) and allows you to list the input data on the screen or printer (Section 2.2), execute the climatic simulation and list the output on the screen or printer (Section 2.3), modify the current input data (Section 2.5), manage input data files (Section 2.6), or exit CLIMSIM (2.0).

If you wish to make corrections to the input data, select option (5) of the Master Menu to bring up the data modification menu. From this menu, choose the appropriate data category, change the item(s) desired, and return to the modification menu. When all corrections are completed proceed from the modification menu back to the Master Menu.

#### 4.2 Viewing and Saving Simulation Results

Once the input data is all correct, select option (3) of the Master Menu to view the predicted environment on the screen. The climatic conditions, as measured by several different parameters described in Section 2.3, will be

listed for each output station.

After viewing this output you will be asked if you wish to see graphical output. If you press "Y" you will have the opportunity to graph the value of each output parameter against distance on the screen and on the plotter (Section 2.4). These graphs help considerably in identifying climatic trends along the airway and changes caused by sources of heat or cooling. If you answer "N" then you will return to the Master Menu. The option to view graphical output is made available after each execution of the simulation routine (options (3) and (4) of the Master Menu).

If you require a permanent record of the simulation, choose option (2) and, when the Master Menu reappears, select option (4). This will list the input data and the output at the printer. A page header block may be placed at the top of each printer page by making the appropriate entries for the CONFIG file (Section 2.1.2). Permanent graphical output can be obtained by producing plots on the plotter and dumping the graphical screen to the printer using the "PrtSc" key (the latter requires that the DOS command "GRAPHICS" be executed prior to running CLMSIM (2.0)).

#### 4.3. Modifying and Saving Input Data

If you anticipate using this input data again, you should save it on disk by selecting option (6) of the Master Menu. This will bring up the data file management menu (Section 2.6) which will allow you to assign a file name and save it on any desired drive. In future CLMSIM (2.0) runs the saved data may be accessed by specifying "data file" as the source of input data (Section 2.1.3) or by entering the data file management menu from the Master Menu.

The current input data may easily be modified by choosing option (5) of the Master Menu, which brings up the data modification menu (Section 2.5). This will allow you to change the airflow or sources of heat or cooling, for example,

and rapidly observe the effects of these changes. This modified data may be saved in place of the previously saved data, if desired, or it can be saved as a separate file with a different name.

Once you have created and saved the basic input data files for a succession of connecting airways, climatic simulation in conjunction with a network analysis program becomes very easy. Simply read in the data file for the first airway, modify the inlet conditions as required, and execute the climatic simulation. The outlet conditions can be used to modify the inlet conditions for the next airway data file that is read in.

If desired, the listed climatic output parameters (Section 2.1.2) can easily be changed at any time without losing the current input data. First, move to the data modification menu and choose option (7), "re-enter data from the beginning". You will be prompted for climatic output parameters, after which you should designate "data file" as the source of input data. Then proceed directly to the Master Menu without reading in any new data.

The current input data is never lost until new input data is either entered from the keyboard or read from a file. More importantly, the current data is never saved unless explicitly done so through the data file management menu.

#### 4.4 Some Practical Observations on Data Acquisition and Correlation Trials

The algorithms and equations employed within the CLIMSIM (2.0) program are based on established theories of heat transfer, thermodynamics and psychrometry. However, as with all computer programs, the precision of the predictions depends entirely upon the accuracy of the input data. Input data must be carefully determined and models must be correlated with existing conditions before further planning exercises are conducted.

#### 4.4.1 Uncertain Input Parameters

All climatic simulation programs, including CLIMSIM (2.0), require input data that may not, initially, be known to the desired degree of accuracy. Parameters such as the ages and depths of the ends of the airway, the volume flow of air and the airway dimensions can be determined with confidence. The data that is less certain include the following:

thermal conductivity: The difficulty here is that laboratory determinations of the thermal properties of rock samples are usually quite different from the values of those same properties in-situ. The value of the effective thermal conductivity of strata in the mine may be two to three times that of laboratory samples of the same rock. Furthermore, it is the effective thermal conductivity that must be used in simulation programs. The reasons for the difference include the migration of strata fluids (water and gas), local geothermal anomalies or radioactive decay. The effective thermal conductivity can be measured in-situ, but this may be time consuming and expensive. An alternate method of gaining a value for effective thermal conductivity is by correlation studies between psychrometric measurements made in the mine and sensitivity trials on CLIMSIM (2.0).

thermal diffusivity: Unless an in-situ value of diffusivity has been determined it is advisable to skip the request for this parameter made by CLIMSIM (2.0) and, instead, enter the density and specific heat of the rock.

wetness factor: The wetness factor is defined as the fraction of rock surface that is wet. This is difficult to measure in practice as rock surfaces may often be only partially wetted. Furthermore, it is usually the case that surfaces which are apparently dry do, in fact, exude water. A wetness factor of

less than 0.04 seldom occurs except, perhaps, in the hygroscopic minerals of evaporite mines.

The dry bulb temperature of the air is particularly sensitive to the wetness of the airway. Fortunately, wet bulb temperature, which is much more important in governing the cooling power of the air, is not affected directly by wetness factor. It is, however, influenced slightly and indirectly by airway wetness in that the dry bulb temperature affects the heat flow into the airway and this, in turn, governs the sigma heat (total heat content) of the air and, hence, the wet bulb temperature.

Here again, correlation trials with CLIMSIM (2.0) will suggest typical wetness factors for any existing mine.

machine utilization: The CLIMSIM (2.0) input requests the full power rating and the percentage utilization of each piece of mechanized equipment. The product of the two is used in determining the corresponding heat output. In practice, the actual full power rating of a machine may deviate considerably from the manufacturer's nominal value, depending upon the age and maintenance of the equipment. Furthermore, the percentage utilization will often require a subjective assessment by the ventilation engineer as machines may fluctuate considerably in their load factor, especially where diesels are employed. A shift by shift record of fuel consumption provides a useful guide.

Yet another matter that may vary from mine to mine is the fraction of diesel power that is emitted as latent heat. This will have little influence on wet bulb temperature (for a given total machine heat) but significant effect on the dry bulb temperature. Once more, actual measurements of wet and dry bulb temperatures and airflows across machines, coupled with correlating runs of CLIMSIM (2.0), will produce typical machine data for that mine.

other sources of heat and humidity: The CLIMSIM (2.0) program will account for strata heat, autocompression, machine heat and any other spot or line sources of heat that have been identified and are provided as input. On several occasions, correlation trials of CLIMSIM (2.0) at a mine have highlighted actual sources of heat and humidity that had not initially been considered. These have included oxidation processes, heat from minerals in transport, lighting fixtures, pipes and cables, drainage channels, sprays, leakage through old workings, wet fill material, and springs of water. The CLIMSIM (2.0) program is a valuable aid in drawing attention to hitherto unidentified sources of heat and humidity.

#### 4.4.2 Correlation Trials

When using CLIMSIM (2.0) for an existing mine or underground facility, it is of utmost importance to conduct correlation trials prior to employing the program for future planning. The correlation trials will include sensitivity runs involving those input parameters of uncertain accuracy and which are discussed in the preceding paragraphs. Experience has shown that such correlations conducted for a few airways in any mine can not only highlight unknown sources of heat and humidity, but also provide a range of typical data values that may then be tested against further airways until sufficient confidence has been established to embark upon planning studies.

There is a definite procedure to follow in conducting sensitivity studies and correlations of CLIMSIM (2.0) output with actual conditions in a mine. The airways chosen for initial correlation should be well established and continuous with no intermediate additions or losses of airflow. Any gradient from horizontal to vertical is acceptable provided that it remains uniform along the length of the airway. The primary trials should seek to provide correlation between CLIMSIM (2.0) results and the effects of strata heat and, perhaps, autocompression. Additional sources of heat that can be quantified easily, such

as metered electrical equipment, may also be included. However, the initial trails should avoid airways that contain diesel equipment or open drainage channels. Such sources of heat should be subject to secondary correlation runs and data acquisition.

Careful measurements of airflow, barometric pressure, and wet and dry bulb temperatures should be made at the intake end of the correlation airway. Additional wet and dry bulb temperatures should also be taken at about 100m intervals (or less) along the airway. All of the other parameters required as input should be ascertained or ascribed initial estimated values.

In comparing the CLIMSIM (2.0) output with the observed temperatures, attention should be focussed first on the wet bulb temperatures. If there is a consistent divergent trend between the computed and measured values then it is probable that a continuous heat source has been over or under-estimated, or perhaps even omitted entirely. Reference should be made to the previous section on other sources of heat and humidity. A check should be carried out on the depths of the airway ends and their corresponding ages (if less than two years). Sensitivity runs should also be made to test the effect of thermal conductivity.

If the observed wet bulb temperatures do not show a smooth trend then the reasons for discontinuities should be investigated. There may be occurrences such as leakage of air or fluids from old workings, machine heat, or increased inflow of fissure water. Correlation exercises with CLIMSIM (2.0) provide a valuable educational experience in tracing sources of heat in the mine.

When reasonable correlation ( $\pm 1$  °C) has been obtained on the wet bulb temperature, attention should be turned to the dry bulb temperature. Any remaining deviations of this parameter will almost certainly be due to the evaporation or condensation of water. If the deviation shows a consistent trend then it is likely that the wetness factor has been wrongly assessed. Sensitivity runs on wetness factor will test for such a condition. More localized

deviations may be caused by inaccurate assessment of the water vapor produced by diesel equipment, or the effects of dust suppression sprays.

Having followed this correlation procedure over a series of airways, the ventilation engineer will have built up a store of information on the values and dispersion of heat sources in his mine. He will also have determined a range of in-situ values of thermal conductivities, wetness factors and contributions of heat and humidity from mechanized equipment. At that stage, forward planning studies may be initiated with confidence levels that have been established through the correlation procedures. Climatic simulations then provide an invaluable tool of unprecedented detail in planning environmental control for hot underground facilities.

## 5. EXAMPLE

### 5.1 Introduction

During the practical application of CLIMSIM (2.0), it is often necessary to follow an airflow route that traverses several contiguous branches of a ventilation network in succession. This route will, typically, commence at the surface access of a downcast shaft or slope, and follow the path of the air along the main intakes and through the work areas, in order to establish the climatic conditions in those areas. If the traverse follows a continuous airflow direction, then the wet and dry bulb temperatures and the barometric pressure predicted at the end of each airway may be used as the inlet conditions for the next branch.

This example of a CLIMSIM (2.0) application illustrates a downcast shaft feeding some of its air into a working level. This, in turn passes its return air into the bottom of a conveyor slope which provides a return route back to surface (Figure 5.1). The "three airway" example allows more of the features and capabilities of CLIMSIM (2.0) to be illustrated than would be practicable in a single airway.

The CLIMSIM (2.0) program handles the effects of autocompression and strata heat automatically. However, as indicated in Section 4.4, the user must provide the data necessary to specify the magnitudes and locations of other sources of heat transfer such as machinery, pipes or coolers. As the purpose of this example is to illustrate the use of CLIMSIM (2.0), it has been assumed that the necessary data acquisition and background calculations associated with the artificial heat additions have been completed. However, an indication of the sources of the data and the type of calculations involved is given.

## 5.2 Layout of Airflow Route

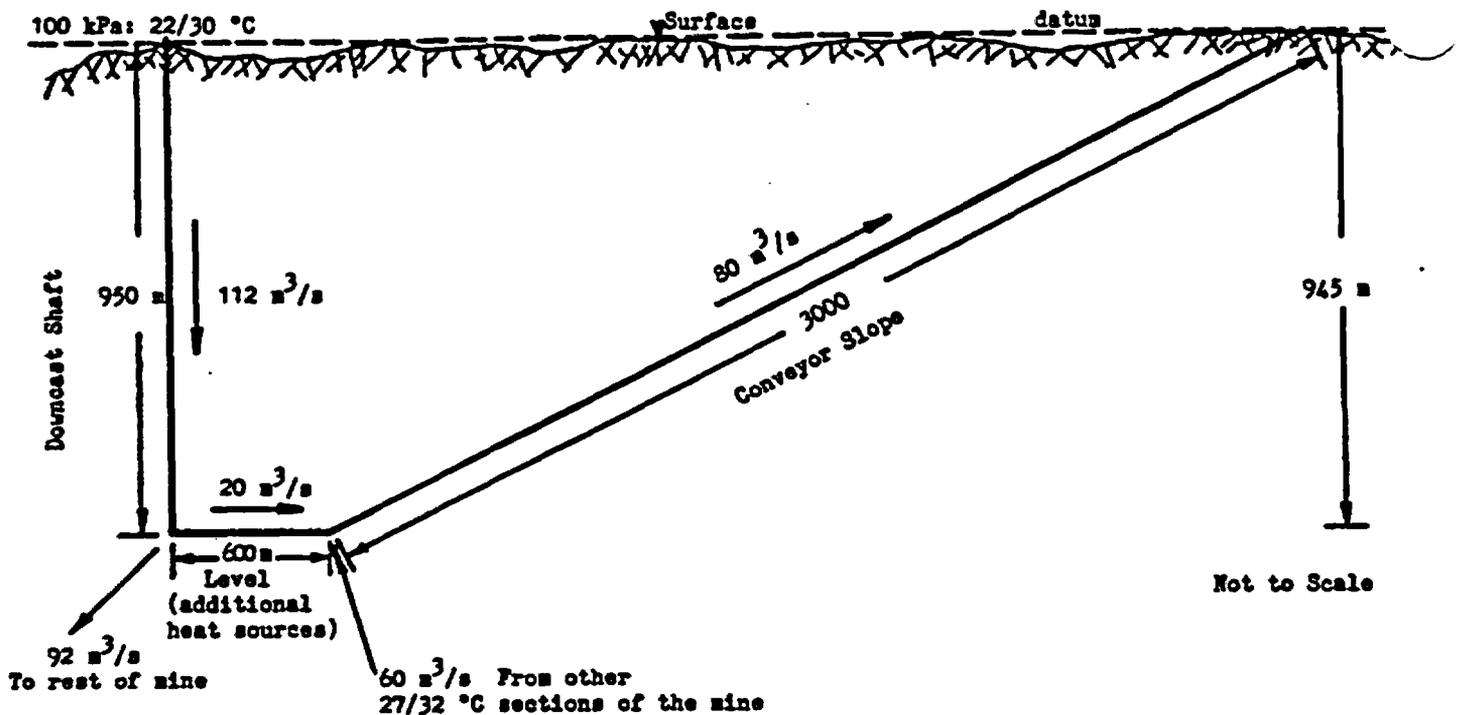


Figure 5.1: Airflow Route Chosen for Analysis.

Figure 5.1 is a schematic of the three contiguous flow paths chosen for analysis. A downcast shaft carrying an airflow of  $112 \text{ m}^3/\text{s}$  delivers  $20 \text{ m}^3/\text{s}$  into a level at a depth of 950 m. The remaining  $92 \text{ m}^3/\text{s}$  provides air to the rest of the mine. The level rises slightly to a depth of 945 m at its return end and contains a number of additional sources of heat. The base of the conveyor slope receives the return air from the level and, also, an additional  $60 \text{ m}^3/\text{s}$  returning from other sections of the mine at a wet/dry bulb temperature of  $27/32^\circ\text{C}$ .

The objective of the analysis is to determine the variation in psychrometric conditions along the three given airways. The other underground openings and surface connections in the mine network are not included in the traverse.

### 5.3 CLIMSIM (2.0) Runs

#### 5.3.1 Downcast Shaft

The data that has been collected for the shaft may be classified as follows:

##### Inlet conditions:

Meteorological records have been scrutinized and have indicated the following mean summer conditions :

barometric pressure	100 kPa
wet bulb temperature	22°C
dry bulb temperature	30°C

The "thermal flywheel" effect of the strata heat sink renders it unnecessary to consider diurnal variations in temperature for this type of exercise.

##### Shaft dimensions:

The shaft cross-section is circular, 6 m in diameter and 950 m deep.

$$\text{Cross-sectional area, } A = \pi 6^2 / 4 = 28.27 \text{ m}^2$$

$$\text{Perimeter, per} = \pi 6 = 18.85 \text{ m}$$

##### Shaft conditions and age:

Concrete lining is employed throughout the shaft and rope guides are fitted. The friction factor (k) has been determined at 0.006 kg/m<sup>3</sup> from a ventilation survey of the shaft. The shaft is nearly dry with only a few damp areas. The estimated wetness factor is 0.05. The shaft has been in operation for five years (1825 days) and contains no sources of heat other than the strata.

##### Thermal parameters:

Borehole probe measurements have shown that the VRT (virgin rock

temperature) at 950 m depth is 51.7 °C, and that the mean geothermal step is 30 m/°C. Hence, the effective VRT at the surface is:

$$51.7 - 950/30 = 20.0 \text{ } ^\circ\text{C}$$

From weighted averaging of the strata in the shaft section,

$$\text{mean thermal conductivity} = 2.00 \text{ W/m } ^\circ\text{C}$$

$$\text{and mean thermal diffusivity} = 2.78 \times 10^{-6} \text{ m}^2/\text{s}$$

Under the guidance of the CLIMSIM (2.0) menu structure (Sections 2.1 and 2.2), all of the shaft data was entered into the computer and saved in a data file. This same information, as summarized on the screen and printer, is shown in Table 5.1.

Execution of the program (Section 2.3) produced the tabular listing shown as Table 5.2. A choice was made to list sigma heat in preference to enthalpy, and VRT rather than dry wall temperature. Additionally, graphical output was selected for air temperatures, pressure, and relative humidity. These are shown Figures 5.2 through 5.4, respectively.—

The flow in the shaft is near adiabatic with an wet bulb temperature lapse rate of  $(25.75 - 22.00)/9.5 = 0.395 \text{ } ^\circ\text{C per 100 m}$  (compared with  $0.41 \text{ } ^\circ\text{C per 100 m}$  for adiabatic flow at the same inlet conditions). The difference indicates that there is a small net loss of heat from the air to the strata.

The dry bulb temperature lapse rate is given as  $(37.40 - 30.00)/9.5 = 0.780 \text{ } ^\circ\text{C per 100 m}$ . At the computed increase in moisture content of  $(14.21 - 13.52) = 0.69 \text{ g/kg}$ , the adiabatic dry bulb lapse rate may be calculated as follows:

$$\text{increase in moisture content, } \Delta x = \frac{0.69}{9.5} = 0.0726 \text{ g/kg per 100 m}$$

The adiabatic dry bulb lapse rate may be calculated as:

$$0.9761 - (2.405 \Delta x) \text{ } ^\circ\text{C per 100 m}$$

Mine Ventilation Services, Inc.

CLIMSIM VERSION 2.0 FINAL FILING  
PAGE NO. \_\_\_\_\_

Job No. \_\_\_\_\_

Sheet \_\_\_\_\_ of \_\_\_\_\_

Job Title \_\_\_\_\_

DESIGNED BY: \_\_\_\_\_ DATE \_\_\_\_\_

Descriptions: \_\_\_\_\_

CHECKED BY: \_\_\_\_\_ DATE \_\_\_\_\_

-----  
**Initial parameters for the prediction of heat and humidity**

**Physical description of example shaft**  
-----

Length = 950 m  
Depth in = 0 m  
Depth out = 950 m  
Cross-sectional area = 28.27 m<sup>2</sup>  
Perimeter = 18.85 m

Friction coeff. = .006 kg/m<sup>3</sup>  
Wetness factor = .05  
Age at inlet = 1825 days  
Age at outlet = 1825 days

**Ventilation at intake**  
-----

Quantity = 112 m<sup>3</sup>/s  
Pressure = 100 kPa

Dry bulb temp. = .30 Deg C  
Wet bulb temp. = .22 Deg C

**Thermal Parameters**  
-----

V.R.T. at inlet = 20 Deg C  
Geothermal step = 30 m/Deg C  
Heat transfer coefficient = 22.952 W/m<sup>2</sup>/Deg C

Conductivity = 2.000 W/m/Deg C  
Diffusivity = 2.780E-06 m<sup>2</sup>/sec

Distance between temperature outputs = 50 m - 19 output stations

**Heat Sources**  
-----

Virgin rock temperature is the only heat source for this simulation.

Table 5.1: Input Data for Shaft

Mine Ventilation Services, Inc.

CLIMSIM VERSION 2.0

FINAL FILING  
PAGE NO. \_\_\_\_\_

Job No. \_\_\_\_\_

Sheet \_\_\_\_\_ of \_\_\_\_\_

Job Title \_\_\_\_\_

DESIGNED BY: \_\_\_\_\_ DATE \_\_\_\_\_

Descriptions: \_\_\_\_\_

CHECKED BY: \_\_\_\_\_ DATE \_\_\_\_\_

Predicted Environment: example shaft

dist (m)	dry bulb (C)	wet bulb (C)	moist cont (g/kg)	rel hum (%)	press (kPa)	den (kg/m3)	sigma heat (kJ/kg)	vrt (C)	ACP (W/m2)	eff tmp (C)
0	30.00	22.00	13.44	49.85	100.000	1.140	63.25	20.0	1409	20.21
50	30.40	22.20	13.47	49.11	100.557	1.143	63.72	21.7	1390	20.62
100	30.79	22.40	13.50	48.38	101.115	1.148	64.19	23.3	1371	21.03
150	31.19	22.60	13.53	47.65	101.677	1.152	64.67	25.0	1351	21.43
200	31.59	22.80	13.56	46.96	102.240	1.157	65.14	26.7	1332	21.83
250	31.99	23.00	13.59	46.27	102.806	1.162	65.62	28.3	1312	22.22
300	32.39	23.20	13.62	45.60	103.375	1.167	66.10	30.0	1292	22.61
350	32.79	23.40	13.65	44.94	103.945	1.172	66.58	31.7	1272	22.99
400	33.19	23.60	13.69	44.29	104.519	1.177	67.07	33.3	1252	23.36
450	33.59	23.81	13.72	43.65	105.094	1.182	67.56	35.0	1232	23.73
500	34.00	24.01	13.76	43.03	105.672	1.187	68.05	36.7	1212	24.10
550	34.40	24.21	13.80	42.42	106.253	1.192	68.54	38.3	1191	24.46
600	34.80	24.42	13.83	41.82	106.836	1.197	69.04	40.0	1171	24.82
650	35.20	24.62	13.87	41.23	107.421	1.202	69.53	41.7	1150	25.17
700	35.61	24.82	13.91	40.65	108.009	1.206	70.03	43.3	1129	25.51
750	36.01	25.03	13.95	40.09	108.599	1.211	70.53	45.0	1108	25.85
800	36.42	25.23	13.99	39.53	109.192	1.216	71.04	46.7	1087	26.19
850	36.82	25.43	14.03	38.99	109.787	1.221	71.55	48.3	1066	26.52
900	37.23	25.64	14.07	38.46	110.385	1.226	72.06	50.0	1045	26.85
950	37.64	25.84	14.11	37.93	110.985	1.232	72.57	51.7	1023	27.18

Sensible heat flow from rock surface to air = -198.5 kW  
 Latent heat flow from rock surface to air = 211.6 kW  
 Total heat flow from rock surface to air = 13.1 kW

Table 5.2: Tabular Output for the Downcast Shaft

example shaft

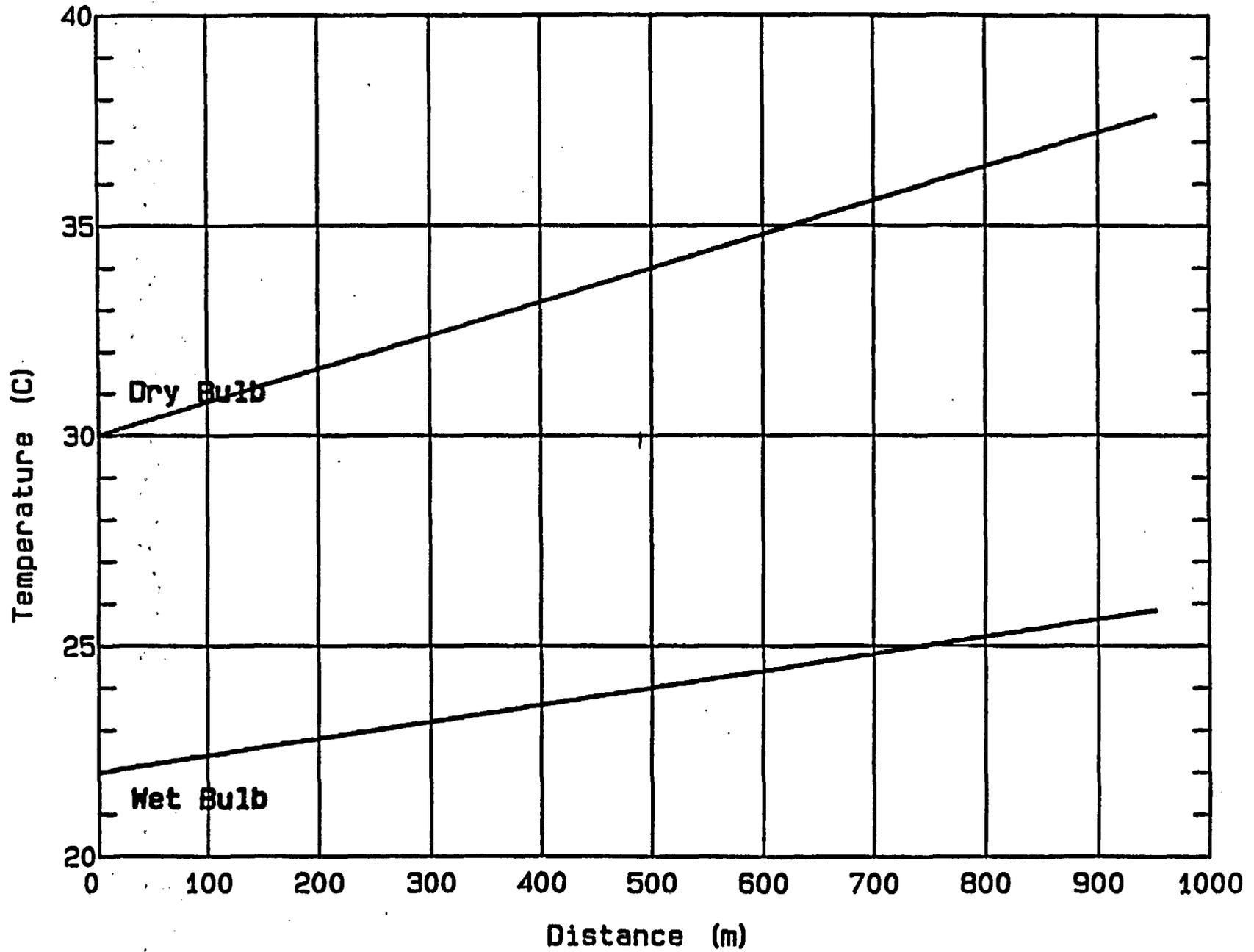
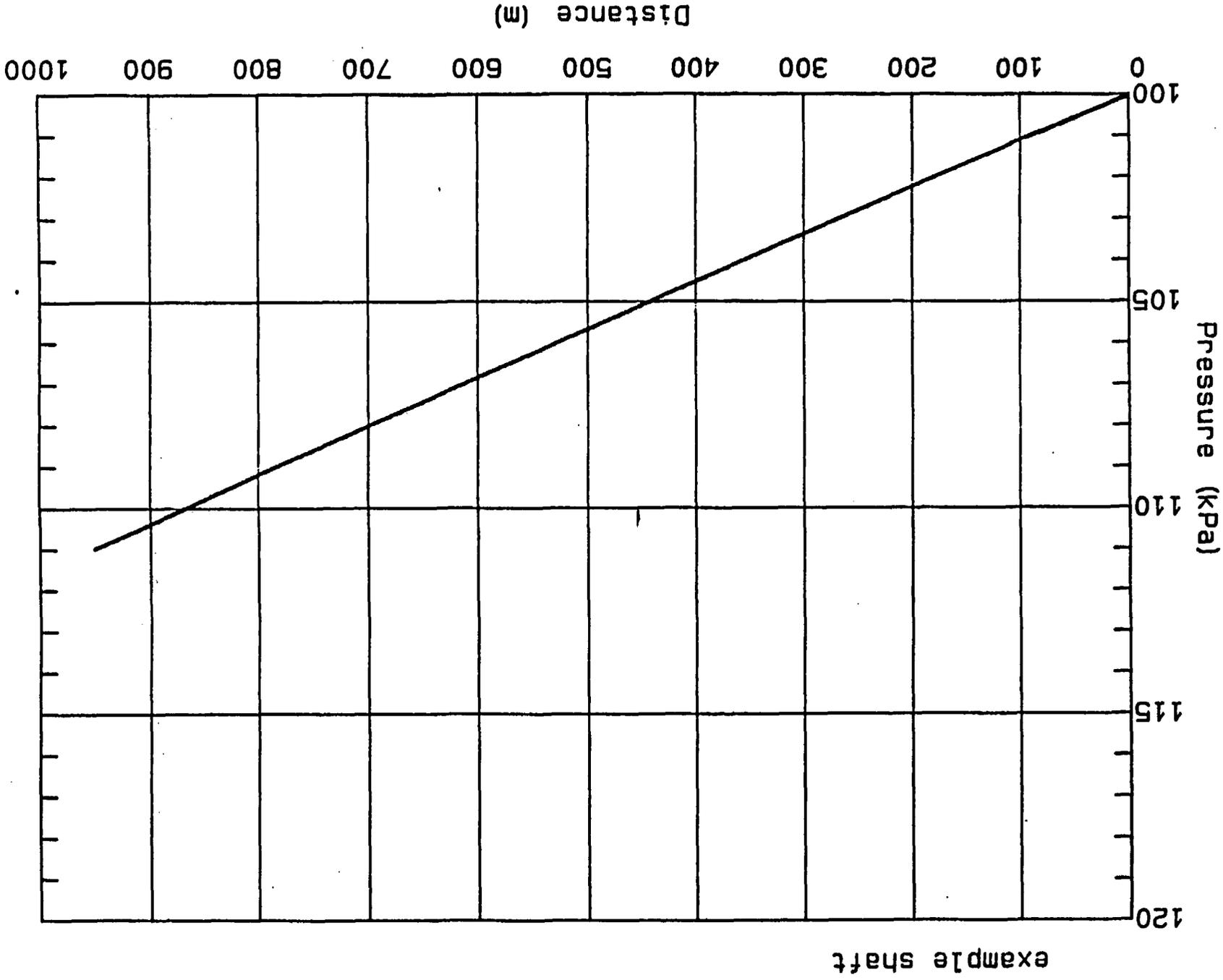


Figure 5.2: Air Temperature in Shaft

Figure 5.3: Barometric Pressure in Shaft



example shaft

example shaft

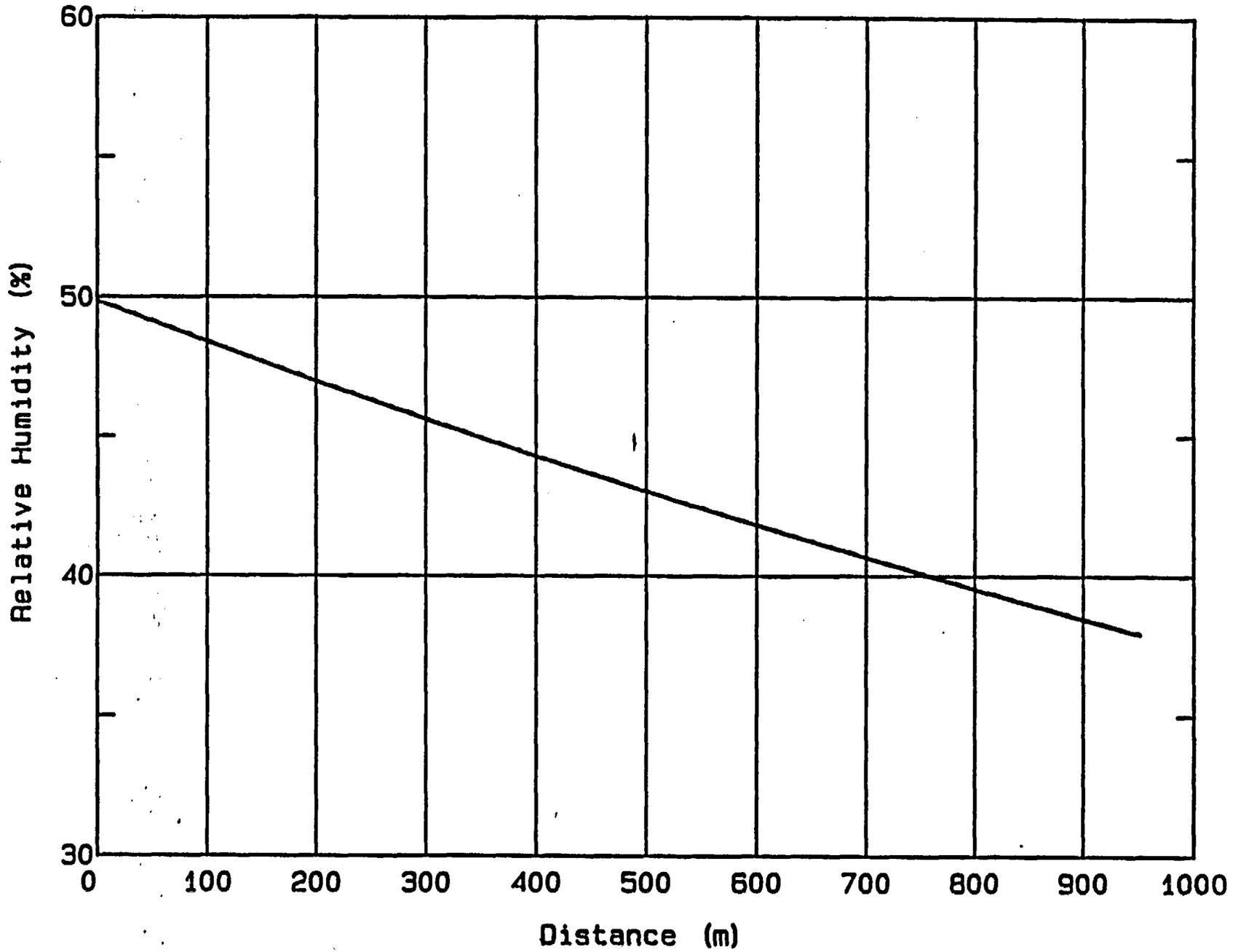


Figure 5.4: Relative Humidity in Shaft

(reference McPherson, M.J. Mine Ventilation Planning in the 1980's.

International Journal of Mining Engineering, 1984, 2, p. 203.)

$$\text{or } 0.9761 - (2.405 \times 0.0726) = .80 \text{ } ^\circ\text{C per 100 m}$$

This is slightly above the computed value, indicating, again, a small heat loss to the strata.

These calculations of temperature lapse rates are simple examples of the many subsidiary analyses that may be conducted on the results of a CLIMSIM (2.0) run. Details of such analyses are included in the companion manual on verification of the CLIMSIM (2.0) program.

### 5.3.2 Level

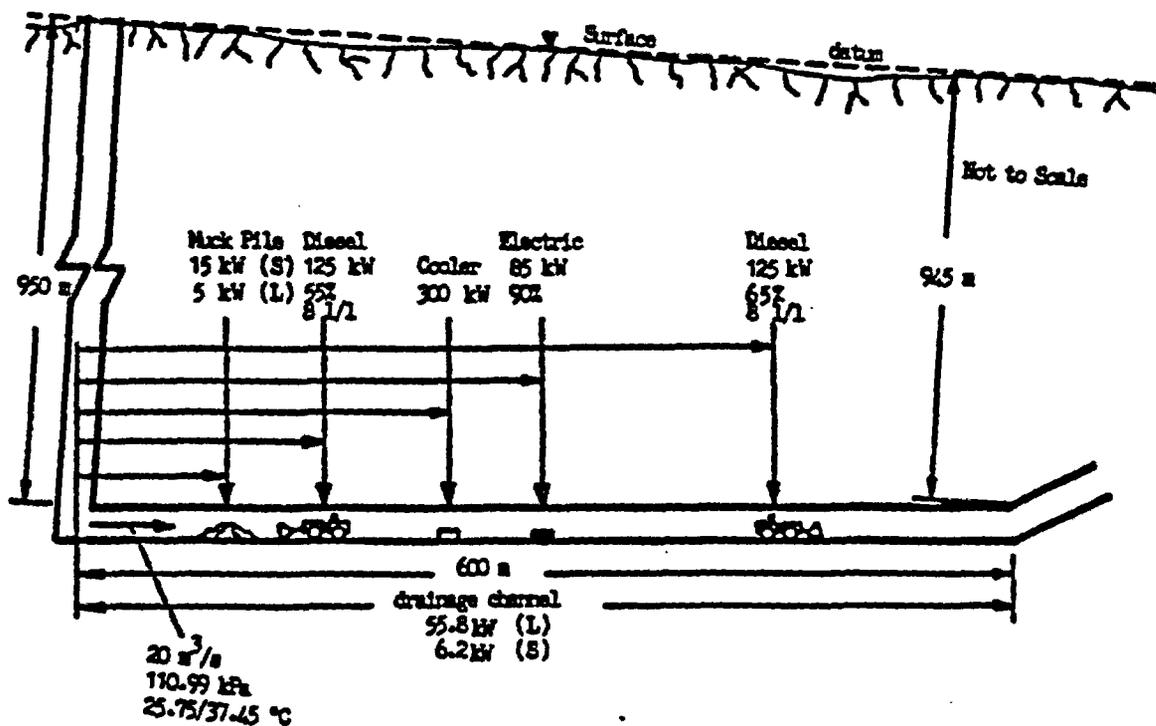


Figure 5.5: Distribution of Heat Sources in the Level.

Figure 5.5 illustrates that the level rises through a vertical distance of 5 m over its full length of 600 m. The additional data required for the corresponding CLIMSIM (2.0) run was collated as follows:

#### Inlet conditions:

An airflow of 20 m<sup>3</sup>/s enters the level from the base of the downcast shaft. The inlet conditions were read from the bottom line of Table 5.2 (i.e. the barometric pressure and temperatures of the air leaving the shaft bottom).

barometric pressure:	110.991 kPa
wet bulb temperature:	25.75 °C
dry bulb temperature:	37.40 °C

#### Airway dimensions:

The level is rectangular in cross section, 5 m wide and 4 m high.

$$\text{Area} = 5 \times 4 = 20 \text{ m}^2$$

$$\text{Perimeter} = 2(5 + 4) = 18 \text{ m}$$

#### Airway conditions and age:

The level has been driven by drill and blast methods, leaving a fairly rough, unlined rock surface. The friction factor is estimated at  $0.016 \text{ kg/m}^3$ .

Conditions are wet with free water on the floor in many areas. The overall wetness factor is judged to be 0.2 based on observations in other levels of the mine with similar conditions.

The level has only recently connected through into the conveyor slope. Its age at the inlet is 400 days and, at the outlet, 35 days.

#### Additional sources of heat:

Figure 5.5 shows the locations of five non-strata sources of additional heat along with one heat exchanger installed to cool the air. The distances given in the following paragraphs are measured from the inlet end of the level.

(i) Muck pile at 100 m.

The heat transfer from a muck pile depends upon the area of broken rock exposed, its surface temperature and wetness, and the psychrometric condition and local velocity of the airstream.

Psychrometric measurements taken across slightly damp muckpiles in other sections of the mine have produced an empirical estimate that 15 kW of sensible heat and 5 kW of latent heat will be added to the airstream from this source.

(ii) Diesel no. 1 at 160 m.

This has a nominal full-load mechanical output of 125 kW, but the

machine is utilized only 55 percent of each working shift. Tests have shown that the diesel engine produces 8 liters (liquid equivalent) of water vapor for each liter of fuel consumed.

(iii) Cooler at 240 m.

This finned tube heat exchanger has a cooling capacity of 300 kW and remains operational at all times.

(iv) Electrical equipment at 300 m.

The electrical item has a full power consumption of 85 kW, but it runs at only 90 per cent full load.

(v) Diesel no. 2 at 450 m.

The second diesel also has a full power rating of 125 kW and produces 8 liters (liquid equivalent) of water vapor per liter of fuel consumed. However, this machine operates at 65 percent full load when averaged over a shift.

(vi) Drainage channel.

An uncovered drainage channel, 0.3m wide and carrying 0.76 liter/s of water, runs the full length of the level. A rough approximation to the heat transfer from this source may be made by assuming inlet and exit temperatures for the water. For example, if it is assumed that water enters the ditch at 50 °C and cools to 32 °C before leaving the level, then:

$$\begin{aligned}\text{Heat flow} &= \text{mass flow} \times \text{specific heat} \times \text{temperature fall} \\ &= 0.76 \times 4.187 \times (50 - 32) \\ &= 57 \text{ kW}\end{aligned}$$

A computer program has been developed to compute heat exchange between drainage channels and the ventilating airstream (MVS report to KE/PB, September, 1985. "Heat exchange between water in a drainage channel and airflow in an underground airway"). Employing the program for this example gave a heat flow of 62 kW from the water in the channel, of which 90 per cent (55.8 kW) was latent heat, and the remaining 6.2 kW was sensible heat.

Rock thermal properties:

The rock surrounding the level has an effective (in-situ) thermal conductivity of 4.433 W/m°C, a specific heat of 950 J/kg°C and a density of 2100 kg/m<sup>3</sup>. Entering these values enables CLIMSIM (2.0) to compute the thermal diffusivity of the rock as:

$$\frac{4.433}{950 \times 2100} = 2.222 \times 10^{-6} \text{ m}^2/\text{s}$$

Borehole data indicates that the VRT at the inlet to the level is 51.7 °C (also shown at the bottom of Table 5.2). The geothermal step remains at 30 m/°C.

Table 5.3 shows the input data as reproduced by CLIMSIM (2.0), and Table 5.4 gives the corresponding tabular output. For this run, the dry wall temperature was selected for output listing in preference to VRT, and effective temperature was selected rather than wet bulb globe temperature. Graphical outputs of temperatures, moisture content, relative humidity, sigma heat, dry wall temperature and air cooling power are reproduced in Figures 5.6 through 5.11 respectively. An examination of the output table and the graphs provides a quantified and detailed analysis of the variation in climate throughout the level. The effects of the additional heat sources and cooler are especially highlighted by the graphical output. CLIMSIM (2.0) draws attention to the

interplay between variables. For example, on comparing the temperature and moisture content plots (Figures 5.6 and 5.7), it may be seen that the rate of increase of moisture content reduces downstream of the cooler, (i.e. the rate of evaporation is lower at reduced air temperatures). Figure 5.8 shows that the relative humidity almost reached 100 percent at the outlet from the cooler. Had a higher duty cooler been used, the moisture content curve would have dropped sharply at the cooler, due to condensed water leaving the system.

The most important parameters produced by CLIMSIM (2.0) are the indices of heat stress. Figure 5.11 shows that discomfort may be experienced by unclimatized personnel towards the return end of the level where the Air Cooling Power falls below  $300 \text{ W/m}^2$ . It is also clear that the diesel equipment rapidly erodes the cooling power of the air, and the conditions in the level would be untenable without air conditioning.

The data file structure and modification menus enable sensitivity trails to be carried out within about one minute on an IBM PC AT. In this example, the simulation of the level may be repeated successively in order to investigate the effects of replacing the diesels by electrical equipment, relocating the cooler, varying the airflow, or any other exercise that may be conducted in an attempt to improve environmental conditions or reduce costs.

Mine Ventilation Services, Inc. CLIMSIM VERSION 2.0 FINAL FILING  
 Job No. \_\_\_\_\_ Sheet \_\_\_\_ of \_\_\_\_ PAGE NO. \_\_\_\_\_  
 Job Title \_\_\_\_\_ DESIGNED BY: \_\_\_\_\_ DATE \_\_\_\_\_  
 Description: \_\_\_\_\_ CHECKED BY: \_\_\_\_\_ DATE \_\_\_\_\_

Initial parameters for the prediction of heat and humidity

Physical description of LEVELEX

Length = 600 m Friction coeff. = .016 kg/m<sup>3</sup>  
 Depth in = 950 m Wetness factor = .2  
 Depth out = 945 m Age at inlet = 400 days  
 Cross-sectional area = 20 m<sup>2</sup> Age at outlet = 35 days  
 Perimeter = 18 m

Ventilation at intake

Quantity = 20 m<sup>3</sup>/s Dry bulb temp. = 37.4 Deg C  
 Pressure = 110.931 kPa Wet bulb temp. = 25.75 Deg C

Thermal Parameters

V.R.T. at inlet = 51.7 Deg C Conductivity = 4.433 W/m/Deg C  
 Geothermal step = 30 m/Deg C Diffusivity = 2.222E-06 m<sup>2</sup>/sec  
 Heat transfer coefficient = 15.449 W/m<sup>2</sup>/Deg C

Distance between temperature outputs = 50 m - 12 output stations

Heat Sources

Non-machine spot heat sources

No.	Distance From intake end (m)	Sensible Heat Load (kW)	Latent Heat Load (kW)
1	100	15.00	5.00
2	240	-300.00	0.00

Machine spot heat sources

No.	Distance from intake (m)	Full load power output (kW)	Percent utilization at equiv. full load	Diesel or Electric
3	160	125.00	55.0	Diesel
Amount of water emitted by diesel = 8 liters water/liter fuel				
4	300	85.00	90.0	Electric
5	450	125.00	65.0	Diesel
Amount of water emitted by diesel = 8 liters water/liter fuel				

Linear heat sources

No.	Distance from intake end (m)	Length of Source (m)	Sensible Heat Load (kW)	Latent Heat Load (kW)
1	0	600	6.20	55.80

Table 5.3: Input Data for Level

Mine Ventilation Services, Inc.

CLIMSIM VERSION 2.0 FINAL FILING  
PAGE NO. \_\_\_\_\_

Job No. \_\_\_\_\_

Sheet \_\_\_\_\_ of \_\_\_\_\_

Job Title \_\_\_\_\_

DESIGNED BY: \_\_\_\_\_ DATE \_\_\_\_\_

Description: \_\_\_\_\_

CHECKED BY: \_\_\_\_\_ DATE \_\_\_\_\_

**Predicted Environment: LEVEL EX**

dint	dry	wet	moist	rel	press	den	enthal	dwall	ACP	eff
(m)	bulb (C)	bulb (C)	cont (g/kg)	hum (%)	(kPa)	(kg/m3)	(kJ/kg)	tmp (C)	(W/m2)	tmp (C)
0	37.40	25.75	14.06	38.28	110.991	1.234	73.72	37.4	446	28.23
Start 600 m linear source no. 1 sensible heat = 6.2 kW, latent heat = 55.8 kW										
50	36.50	25.92	14.73	42.07	110.985	1.236	74.49	37.3	440	27.98
100	35.74	26.10	15.34	45.65	110.979	1.239	75.29	36.6	436	27.78
After spot source no. 1 sensible heat = 15.00 kW, latent heat = 5.00 kW										
150	35.66	26.49	16.01	47.78	110.974	1.239	76.93	36.5	421	27.93
After spot source no. 3 sensible heat = 82.84 kW, latent heat = 111.72 kW										
200	38.22	28.60	18.49	47.80	110.968	1.227	85.93	39.0	320	30.24
After spot source no. 2 sensible heat = -300.00 kW, latent heat = 0.00 kW										
250	25.71	25.70	19.06	99.89	110.962	1.223	74.38	27.2	496	22.01
300	26.40	25.97	19.20	96.58	110.956	1.276	75.45	27.9	482	22.67
After spot source no. 4 sensible heat = 76.50 kW, latent heat = 0.00 kW										
350	29.85	27.02	19.42	79.93	110.950	1.261	79.62	31.2	424	25.52
400	30.17	27.26	19.69	79.51	110.944	1.259	80.65	31.5	412	25.86
450	30.51	27.51	19.97	79.05	110.938	1.258	81.71	31.9	400	26.21
After spot source no. 5 sensible heat = 98.06 kW, latent heat = 131.87 kW										
500	34.51	29.90	22.53	70.91	110.933	1.239	92.43	35.7	275	29.76
550	34.62	30.11	22.89	71.56	110.927	1.239	93.46	36.0	263	29.96
600	34.82	30.35	23.25	71.83	110.921	1.238	94.61	36.4	250	30.22

Sensible heat flow from rock surface to air = -41.8 kW  
 Latent heat flow from rock surface to air = 244.8 kW  
 Total heat flow from rock surface to air = 202.9 kW

Final VRT = 51.5 Deg. C

Table 5.4: Tabular Output for Level

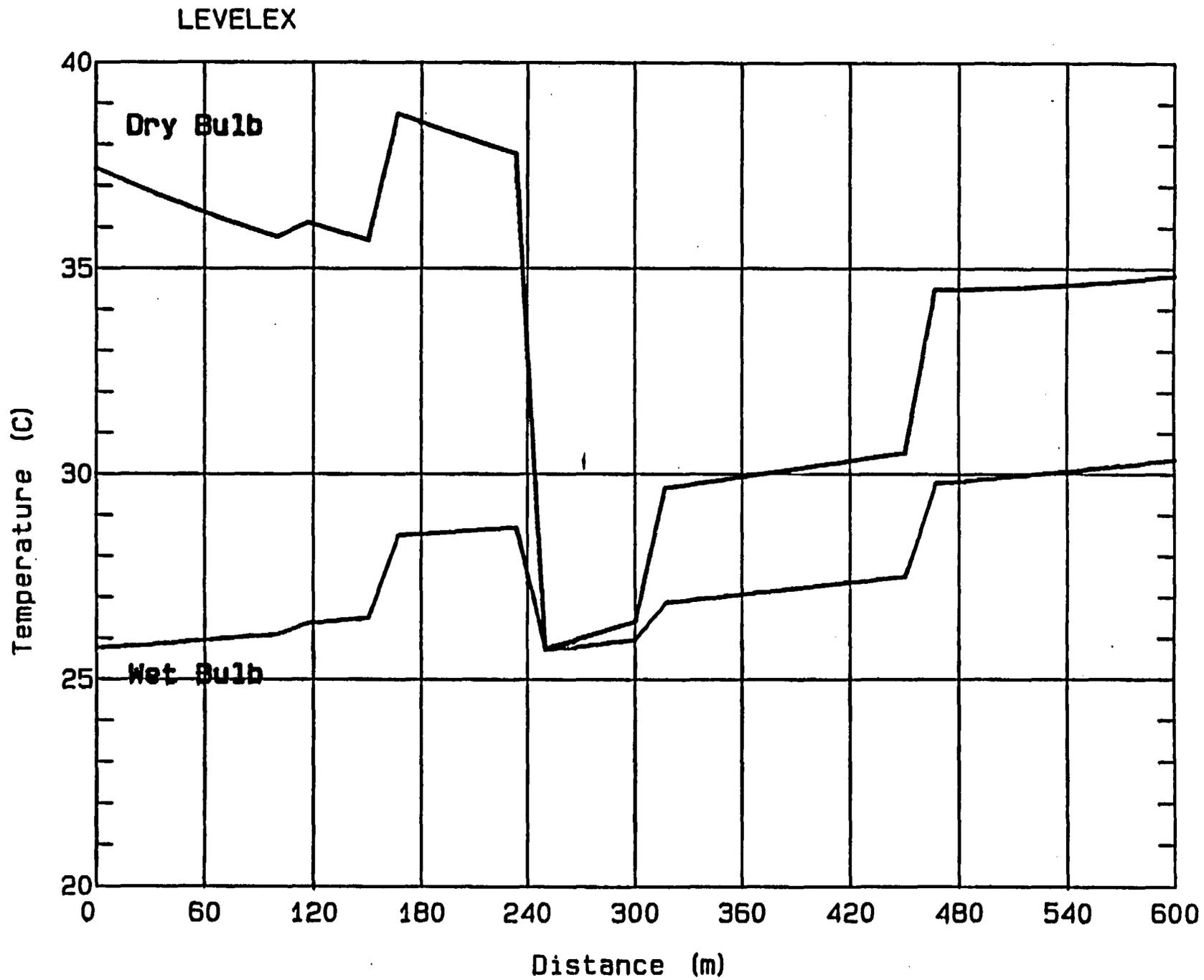


Figure 5.6: Air Temperature in Level

LEVELEX

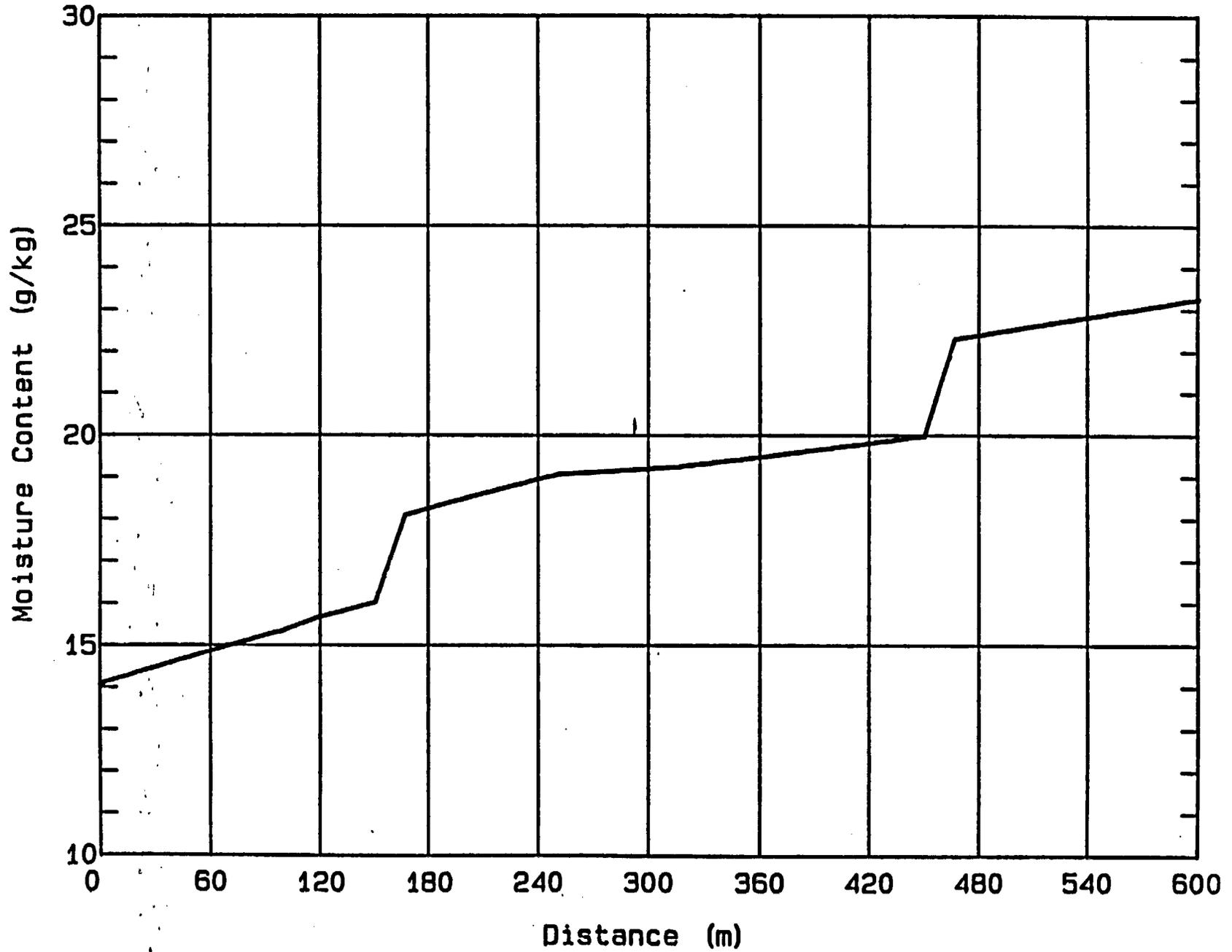


Figure 5.7: Moisture Content of Air in Level

LEVELEX

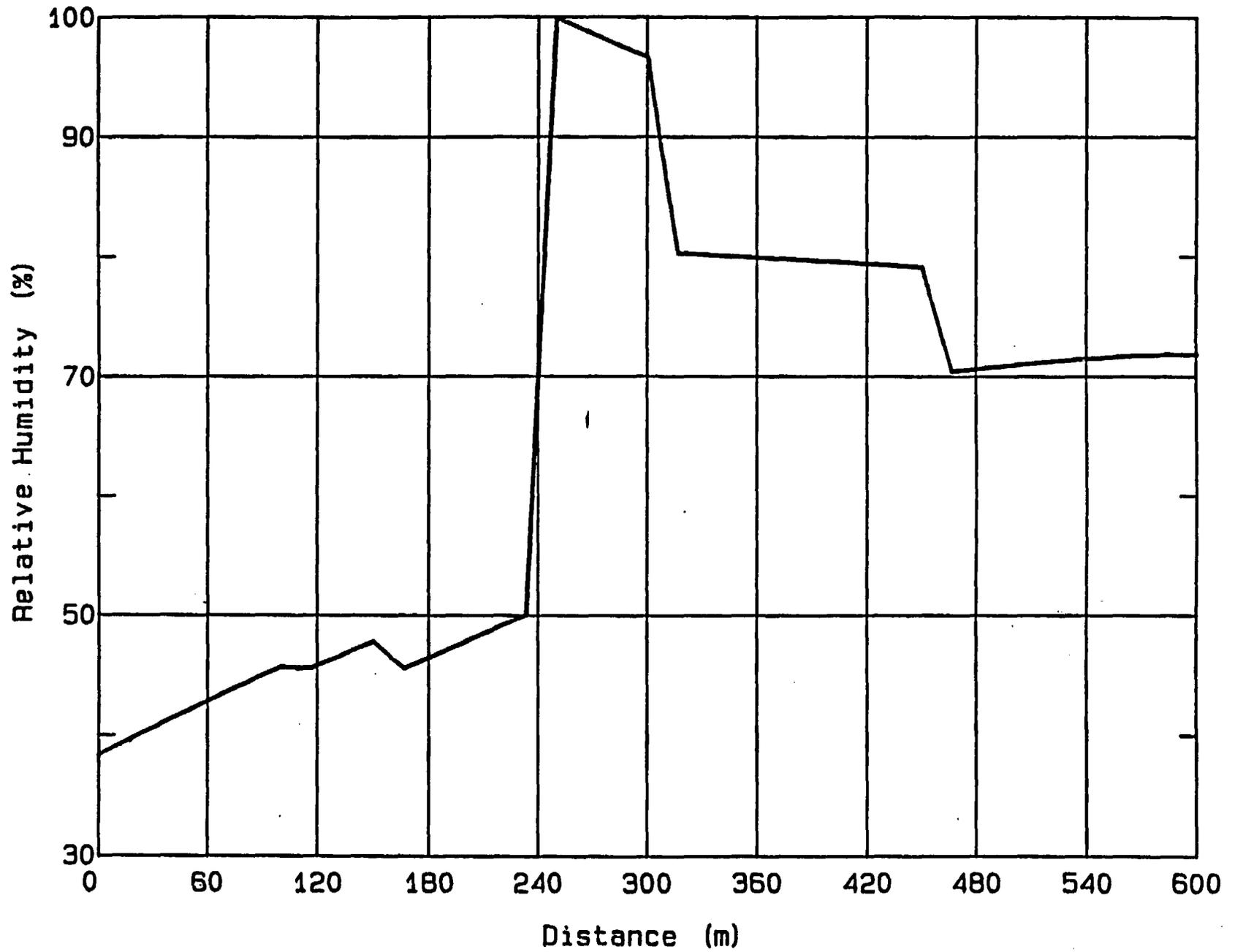


Figure 5.8: Relative Humidity in Level

LEVELEX

-69-

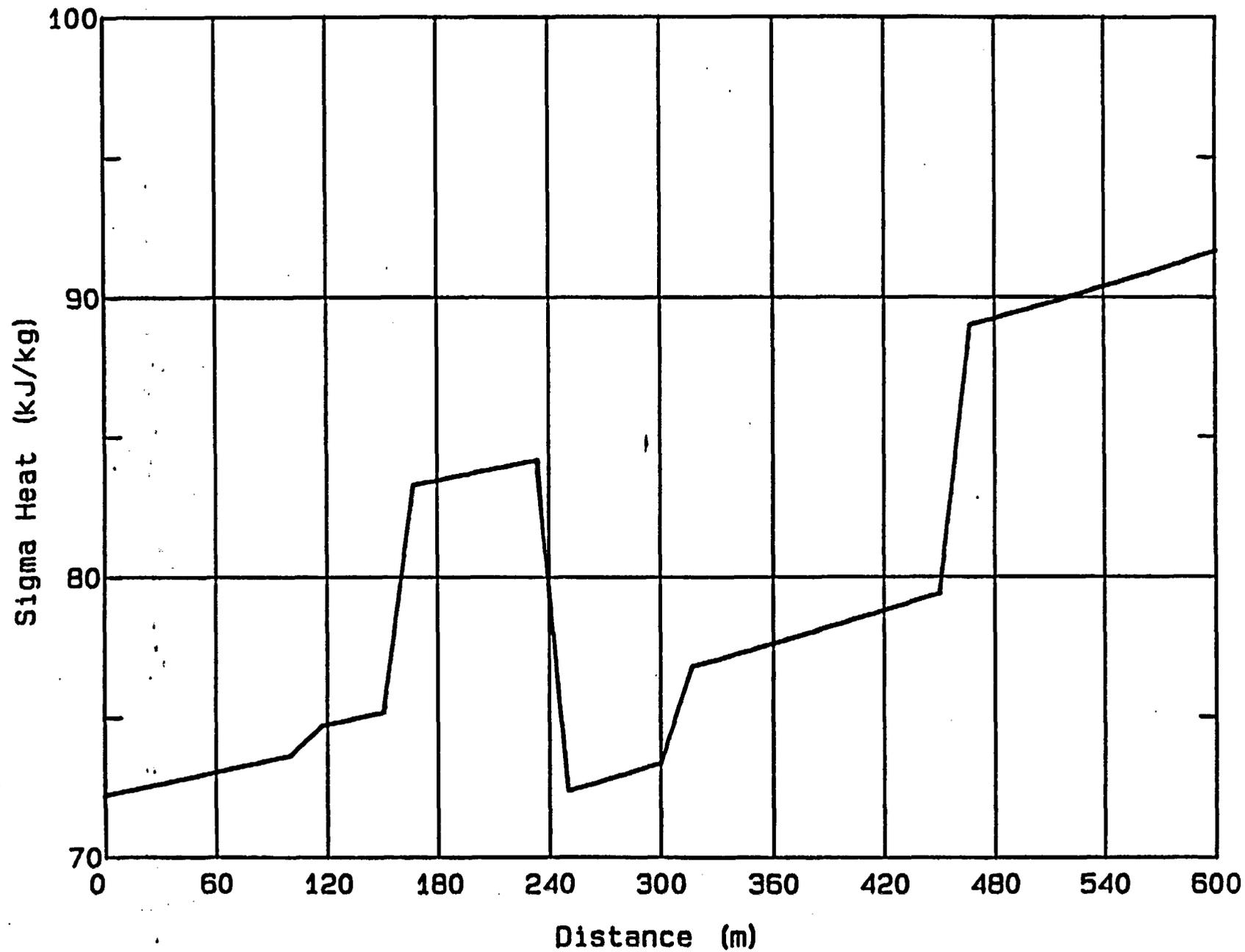


Figure 5.9: Sigma Heat of Air in Level

LEVELEX

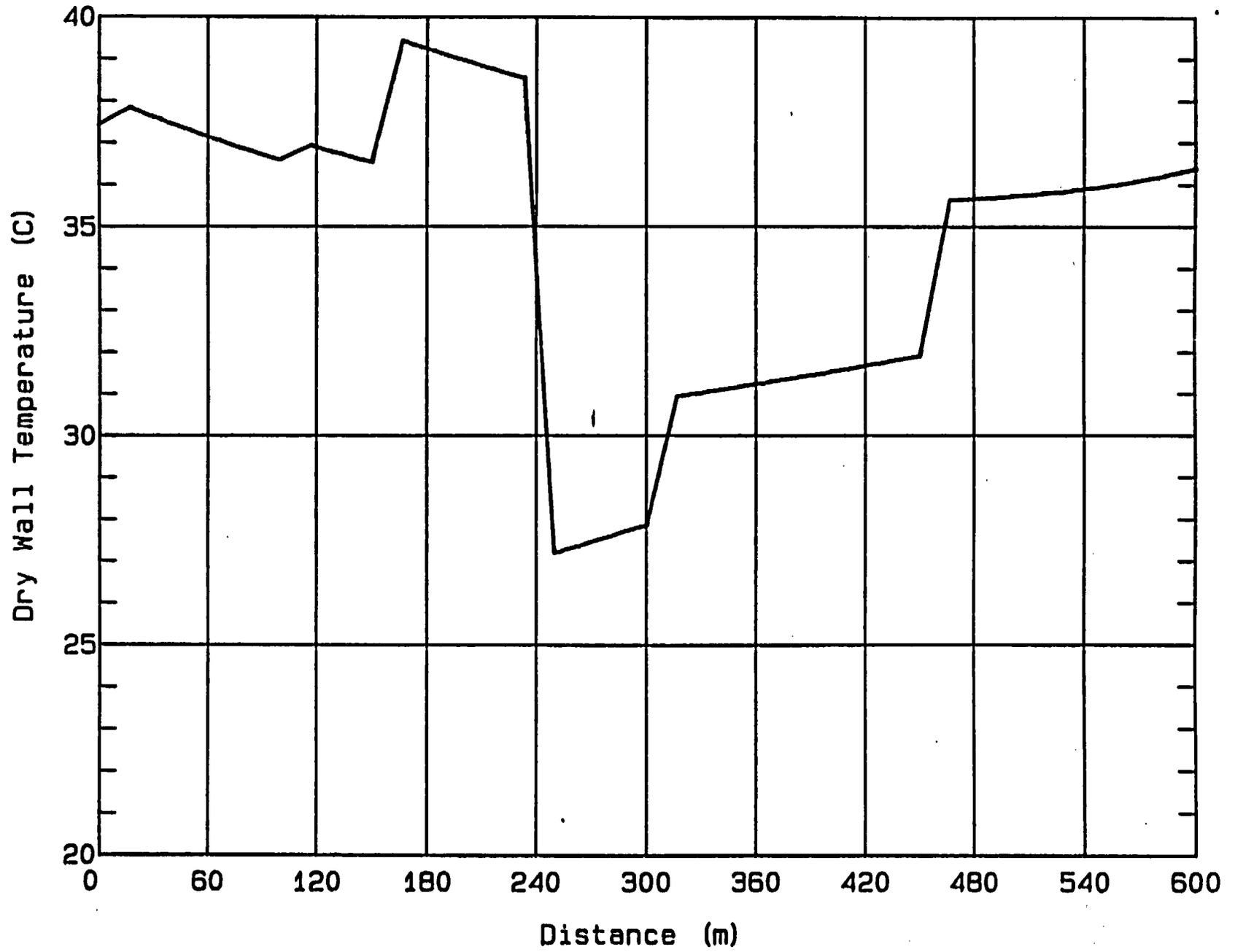


Figure 5.10: Temperature of Dry Rock Surface in Level

LEVELEX

-71-

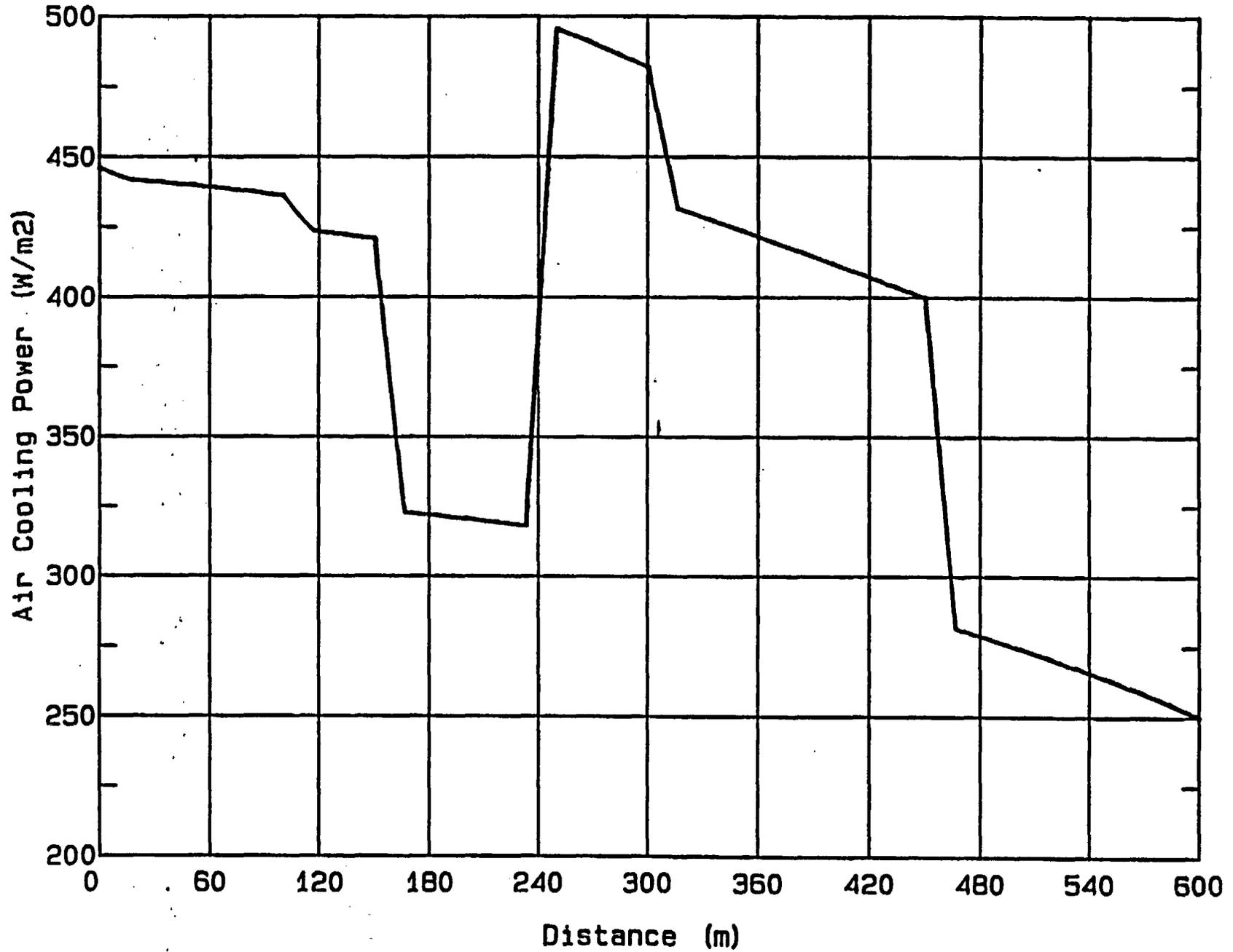


Figure 5.11: Air Cooling Power in Level

### 5.3.3 Conveyor slope

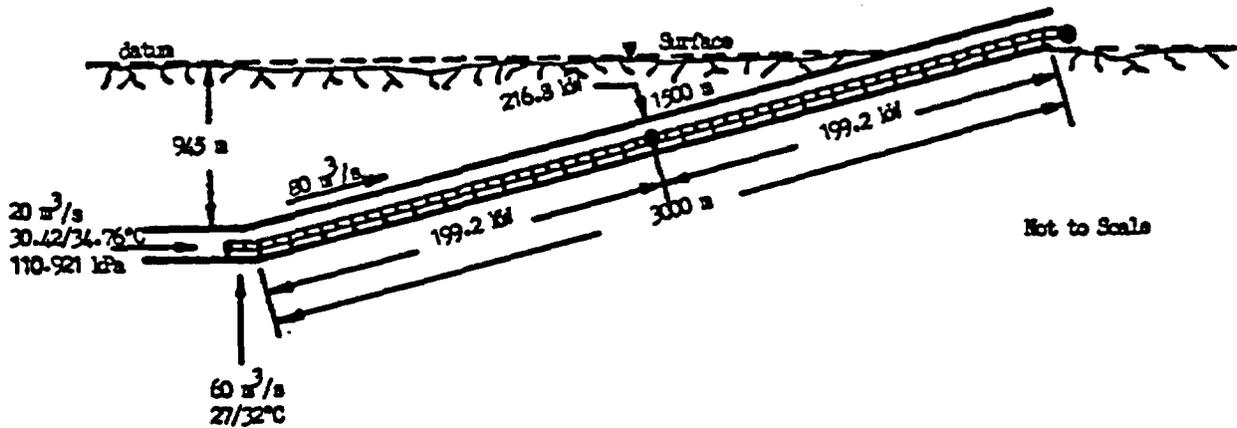


Figure 5.12: Locations of Additional Heat Sources in Conveyor Slope.

The 3000 m conveyor slope ascends uniformly from a depth of 945 m to the surface and carries a return airflow of 80 m<sup>3</sup>/s, including 20 m<sup>3</sup>/s from the level (Figure 5.12). The slope contains two conveyors in tandem, each 1500 m long. Hence, one gearhead/motor unit is located at the surface portal and has no influence on the slope climate, while the other is sited in the mid-point of the drift.

The data for the conveyor slope was collated as follows:

#### Inlet conditions:

As shown in Figure 5.12, the base of the slope receives 20 m<sup>3</sup>/s at 30.42/34.76 °C from the level (see also the bottom line of Table 5.4), and 60 m<sup>3</sup>/s at 27/32 °C from other return airways. The temperatures of the mixture are given approximately as:

$$\text{wet bulb temperature} = \frac{(20 \times 30.42) + (60 \times 27)}{80} = 27.85^\circ\text{C}$$

and,

$$\text{dry bulb temperature} = \frac{(20 \times 34.76) + (60 \times 32)}{80} = 32.69^\circ\text{C}$$

The barometric pressure is the same as that at the return end of the level (Table 5.4, i.e. 110.921 kPa).

Airway dimensions:

Effective cross-sectional area  
(having made allowance for the conveyor) = 13.5 m<sup>2</sup>  
Perimeter of rock surface = 16 m

Airway conditions and age:

The conveyor slope is arched in shape with a fairly smooth lining and has a friction factor of 0.01 kg/m<sup>3</sup>. There is no free running water in the slope; however, there are damp areas on the walls and floor giving an estimated wetness factor of 0.1.

The slope was mined upwards. The age is 730 days at the base and 450 days at the portal.

Additional sources of heat:

There are no non-strata sources of heat apart from the conveyors. The calculation of heat load from each conveyor proceeds as follows:

Maximum capacity	800 tons/hr
i.e. $M = \frac{800 \times 1000}{3600}$	= 222.2 kg/s
Belt width	= 1 m
Belt speed	u = 5 m/s
Mass of empty belt	$\beta = 40 \text{ kg/m}$
Coefficient of friction at rollers	f = 0.032

Efficiency of motor/gearhead  $\eta = 0.85$

Vertical lift of one conveyer =  $945/2 = 472.5$  m

(a) Power required to lift rock

$$\begin{aligned} &= Mg \times \text{vertical lift} \\ &= \frac{222.2 \times 9.81 \times 472.5}{1000} = 1030 \text{ kW} \end{aligned}$$

(b) Frictional heat at roller due to empty belt

$$\begin{aligned} &= L u \beta g f \\ &= \frac{1500 \times 5 \times 40 \times 9.81 \times 0.032}{1000} = 94.2 \text{ kW} \end{aligned}$$

(c) Added frictional heat due to weight of rock

$$\begin{aligned} &= M L g f = \frac{222.2 \times 1500 \times 9.81 \times 0.032}{1000} \\ &= 104.6 \text{ kW} \end{aligned}$$

$$\begin{aligned} \text{Total power taken by motor} &= \frac{[(a) + (b) + (c)]}{\eta} \\ &= \frac{1030 + 94.2 + 104.6}{0.85} = 1446 \text{ kW} \end{aligned}$$

Heat dissipated at motor/gearhead (motor/gear losses)

$$= (1 - 0.85) \times 1446 = 216.8 \text{ kW}$$

Heat dissipated along belt

$$\begin{aligned} &= \text{Total power} - \text{motor losses} - \text{work done against gravity} \\ &= 1446 - 216.8 - 1030 \\ &= 199.2 \text{ kW} \end{aligned}$$

These distributions of conveyor heat are shown on Figure 5.12.

Rock thermal properties:

The strata penetrated by the conveyor drift has weighted mean values of:

thermal conductivity = 2.0 W/m°C

thermal diffusivity =  $2.78 \times 10^{-6}$  m<sup>2</sup>/s

The VRT at a depth of 945 m is 51.5 °C (see bottom of Table 5.4).

Table 5.5 shows the CLIMSIM (2.0) summary of the input data, while Table 5.6 gives the corresponding output. In this case, enthalpy was chosen for output instead of sigma heat, and dry wall rock temperature rather than VRT. Both wet bulb globe temperature and effective temperature were selected for printing in addition to air cooling power.

Here again, the tabular and graphical output may be studied in detail to follow the variations and interplay among the climatic parameters. It is interesting to note that the loss of enthalpy which normally occurs in an ascending airway, is largely counteracted in this case by the thermal energy emitted by the conveyor. Hence, the wet bulb temperature falls more slowly than would otherwise be expected from decompression and heat transfer with the strata. Figure 5.13 shows that the dry bulb temperature falls more rapidly than the wet bulb, and indeed, the two are virtually equal as the air reaches the portal.

Figure 5.14 shows that the relative humidity is almost 100 percent as the air is rejected to the surface atmosphere. This is also indicated as a warning message on Table 5.6 that condensation has commenced. This process is initiated when the wet bulb temperature exceeds the wall rock temperature and may occur at relative humidities of less than 100 percent. Condensation in an airway may cause corrosion, poor travelling conditions, and fogging of the air. Hence, further CLIMSIM (2.0) exercises may be carried out to investigate means of alleviating this problem.

Mine Ventilation Services, Inc.

CLIMSIM VERSION 2.0

FINAL FILING  
PAGE NO. \_\_\_\_\_

Job No. \_\_\_\_\_

Sheet \_\_\_\_\_ of \_\_\_\_\_

Job Title \_\_\_\_\_

DESIGNED BY: \_\_\_\_\_

DATE \_\_\_\_\_

Descriptions: \_\_\_\_\_

CHECKED BY: \_\_\_\_\_

DATE \_\_\_\_\_

Initial parameters for the prediction of heat and humidity

Physical description of SLOPE WITH CONVEYOR

Length = 3000 m  
Depth in = 945 m  
Depth out = 0 m  
Cross-sectional area = 13.5 m<sup>2</sup>  
Perimeter = 15 m

Friction coeff. = .01 kg/m<sup>3</sup>  
Wetness factor = .1  
Age at inlet = 730 days  
Age at outlet = 450 days

Ventilation at intake

Quantity = 80 m<sup>3</sup>/s  
Pressure = 110.921 kPa

Dry bulb temp. = 32.63 Deg C  
Wet bulb temp. = 27.85 Deg C

Thermal Parameters

V.R.T. at inlet = 51.5 Deg C  
Geothermal step = 30 m/Deg C  
Heat transfer coefficient = 57.218 W/m<sup>2</sup>/Deg C

Conductivity = 2.000 W/m/Deg C  
Diffusivity = 2.780E-06 m<sup>2</sup>/sec

Distance between temperature outputs = 200 m - 15 output stations

Heat Sources

Machine spot heat sources

No.	Distance from intake (m)	Full load power output (kW)	Percent utilization at equiv. full load	Diesel or Electric
1	1500	216.80	100.0	Electric

Linear heat sources

No.	Distance from intake end (m)	Length of Source (m)	Sensible Heat Load (kW)	Latent Heat Load (kW)
1	0	1500	193.20	0.00
2	1500	1500	193.20	0.00

Table 5.5: Input Data for Conveyor Slope

Mine Ventilation Services, Inc.

CLIMSIM VERSION 2.0

FINAL FILING

PAGE NO. \_\_\_\_\_

Job No. \_\_\_\_\_

Sheet \_\_\_\_\_ of \_\_\_\_\_

Job Title \_\_\_\_\_

DESIGNED BY: \_\_\_\_\_

DATE \_\_\_\_\_

Descriptions: \_\_\_\_\_

CHECKED BY: \_\_\_\_\_

DATE \_\_\_\_\_

**Predicted Environment: SLOPE WITH CONVEYOR**

dist (m)	dry bulb (C)	wet bulb (C)	moist cont (g/kg)	rel hum (%)	press (kPa)	den (kg/m3)	enthal (kJ/kg)	dwall tmp (C)	ACP (W/m2)	eff tmp (C)
0	32.69	27.85	19.60	68.58	110.921	1.248	83.04	32.7	1089	25.25
Start 1500 m linear source no. 1	sensible heat = 199.2 kW, latent heat = 0 kW									
200	31.70	27.70	19.95	73.22	110.064	1.243	82.91	31.8	1112	24.35
400	30.84	27.56	20.25	77.35	109.210	1.237	82.76	30.9	1136	23.51
600	30.10	27.40	20.48	81.01	108.360	1.230	82.60	30.2	1160	22.71
800	29.44	27.25	20.68	84.24	107.513	1.223	82.41	29.5	1184	21.95
1000	28.86	27.09	20.84	87.10	106.671	1.216	82.21	28.9	1208	21.23
1200	28.33	26.93	20.97	89.62	105.832	1.208	81.99	28.4	1232	20.55
1400	27.85	26.77	21.07	91.84	104.997	1.201	81.74	27.9	1257	19.89
After spot source no. 1	sensible heat = 216.80 kW, latent heat = 0.00 kW									
Start 1500 m linear source no. 2	sensible heat = 199.2 kW, latent heat = 0 kW									
1600	29.41	27.13	21.19	83.74	104.168	1.185	83.69	29.4	1209	21.85
1800	28.73	26.95	21.35	87.02	103.346	1.178	83.39	28.8	1237	21.02
2000	28.13	26.77	21.48	89.92	102.528	1.171	83.08	28.1	1264	20.22
2200	27.58	26.58	21.57	92.49	101.713	1.164	82.74	27.6	1291	19.46
2400	27.08	26.39	21.64	94.76	100.902	1.156	82.38	27.1	1319	18.73
2600	26.61	26.20	21.68	96.79	100.095	1.149	82.01	26.6	1347	18.02
2800	26.18	26.00	21.70	98.61	99.293	1.141	81.61	26.1	1375	17.33
2960	m Along Airway ***** Condensation Started *****									
3000	26.40	26.40	22.51	100.00	98.494	1.132	83.88	26.4	1330	17.79
Sensible heat flow from rock surface to air =							-395.7 kW			
Latent heat flow from rock surface to air =							512.0 kW			
Total heat flow from rock surface to air =							115.8 kW			

Final VRT = 20.0 Deg. C

( Table 5.6: Tabular Output for the Conveyor Slope

# SLOPE WITH CONVEYOR

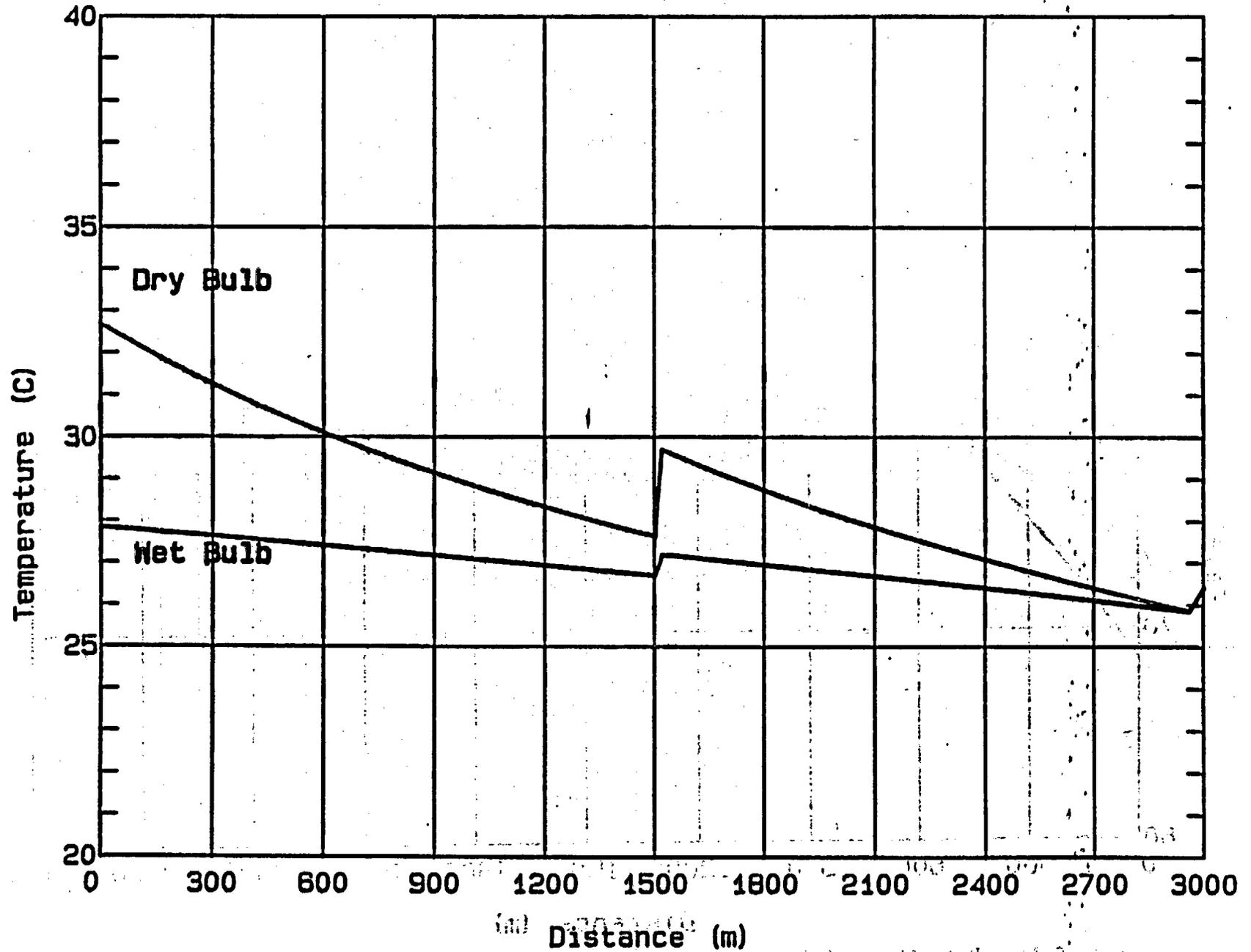


Figure 5.13: Air Temperatures in Conveyor Slope

SLOPE WITH CONVEYOR

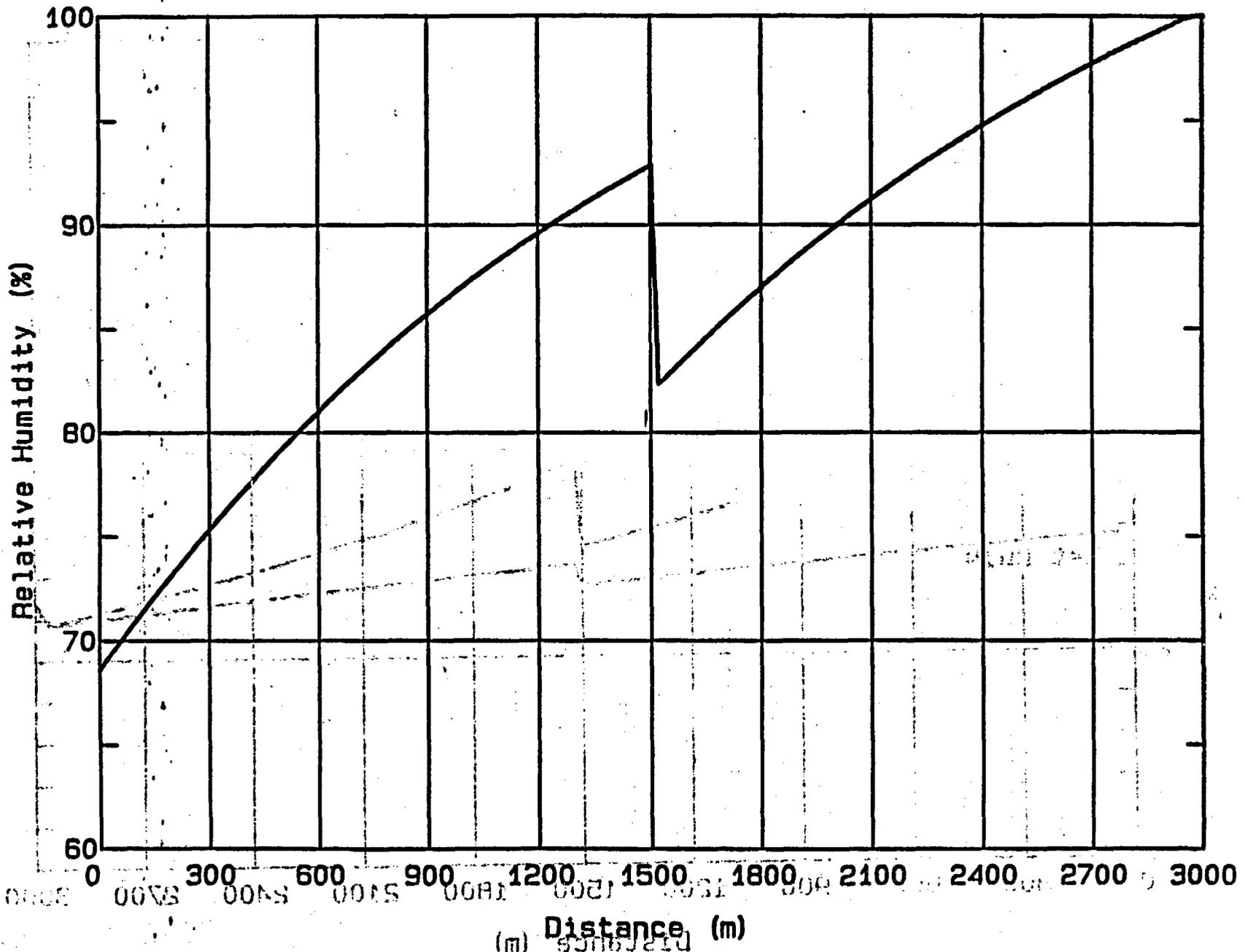


Figure 5.14: Relative Humidity in Conveyor Slope

In this example, no allowance has been made for heat and water vapor from fragmented rock on the conveyor. This may also be included in further exercises.

#### 5.4 Concluding Comments

No illustrative example could possibly encompass the variety of climatic conditions and heat sources that occur in subsurface mines or other facilities. This example was constructed in order to illustrate the methodology of an application of CLIMSIM (2.0), and the type of reasoning involved in preparing the data.

This simulation package is highly flexible, powerful, rapid, and easy to use; however, the user must undertake to spend much more time on the acquisition of data and the conducting of background calculations associated with artificial sources of heat.

6. PROGRAM LISTING

CLMSIM (2.0) is a proprietary program. The listing is available for audit/surveillance conformation at the following address:

Mine Ventilation Services, Inc.  
3717 Mt. Diablo Boulevard  
Suite 101  
Lafayette, California 94549  
U.S.A.  
Telephone: (415) 284-5912  
(415) 284-5924

Section	Acres	Remarks
1	1.0000	
2	1.0000	
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APPENDIX 1

Section	Acres	Remarks
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97	1.0000	
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99	1.0000	
100	1.0000	

**APPENDIX I TABLE OF CONVERSION FACTORS BETWEEN IMPERIAL AND SI UNITS**

<i>Quantity</i>	<i>Imperial to SI</i>		<i>SI to Imperial</i>	
Length	1 ft	= 0.304 8 m	1 m	= 3.280 8 ft
	1 yd	= 0.914 4 m		= 1.093 6 yd
	1 in	= 0.025 4 m		= 39.370 1 in
Area	1 ft <sup>2</sup>	= 0.092 9 m <sup>2</sup>	1 m <sup>2</sup>	= 10.763 9 ft <sup>2</sup>
	1 in <sup>2</sup>	= 0.000 645 m <sup>2</sup>		= 1550.003 in <sup>2</sup>
Acceleration	1 ft/s <sup>2</sup>	= 0.304 8 m/s <sup>2</sup>	1 m/s <sup>2</sup>	= 3.280 8 ft/s <sup>2</sup>
Force	1 lbf	= 4.448 2 N	1 N	= 0.224 8 lbf
	1 ton f	= 9964.02 N		
Velocity	1 ft/s	= 0.304 8 m/s	1 m/s	= 3.280 8 ft/s
	1 ft/min	= 0.005 08 m/s		= 196.85 ft/min
Volume	1 ft <sup>3</sup>	= 0.028 32 m <sup>3</sup>	1 m <sup>3</sup>	= 35.315 ft <sup>3</sup>
	1 yd <sup>3</sup>	= 0.764 56 m <sup>3</sup>		= 1.308 yd <sup>3</sup>
Volume Flow	1 ft <sup>3</sup> /s	= 0.028 32 m <sup>3</sup> /s	1 m <sup>3</sup> /s	= 35.315 ft <sup>3</sup> /s
	1 ft <sup>3</sup> /min	= 0.000 472 m <sup>3</sup> /s		= 2118.9 ft <sup>3</sup> /min
	1 gal/h	= 0.004 56 m <sup>3</sup> /h	1 m <sup>3</sup> /h	= 219.3 gal/h
	1 gal/min	= 0.004 56 m <sup>3</sup> /min	1 m <sup>3</sup> /min	= 219.3 gal/min
		= 4.561 l/min	1 l/min	= 0.2193 gal/min
Mass		= 0.075 77 l/s	1 l/s	= 13.198 gal/min
	1 lb	= 0.453 592 kg	1 kg	= 2.204 62 lb
	1 ton	= 1.016 05 t	1 t	= 0.984 20 ton
Note: 1 metric tonne (t) = 1 000kg = 0.984 207 ton				
Pressure, stress	1 lbf/ft <sup>2</sup>	= 47.880 N/m <sup>2</sup> = Pa	1 N/m <sup>2</sup> = Pa	= 0.020 88 lbf/ft <sup>2</sup>
	1 lbf/in <sup>2</sup>	= 6894.76 N/m <sup>2</sup>		= 0.000 145 lbf/in <sup>2</sup>
	1 in wg	= 249.089 N/m <sup>2</sup>		= 0.004 015 in wg
	1 ft wg	= 2989.07 N/m <sup>2</sup>		= 0.000 3346 ft wg
	1 mm wg	= 9.807 N/m <sup>2</sup>		= 0.101 97 mm wg
	1 in Hg	= 3386.39 N/m <sup>2</sup>		= 0.000 2953 in Hg
	1 mm Hg	= 133.32 N/m <sup>2</sup>		= 0.007 501 mm Hg
	= 1.333 2 mb		= 0.01 mb	
Note: The millibar (1 mb = 100 N/m <sup>2</sup> ) is included here as it is an already familiar metric unit of pressure. It is not, however, an SI unit.				
Airway resistance	1 Atk	= 0.059 71 Ns <sup>2</sup> /m <sup>6</sup>	1 Ns <sup>2</sup> /m <sup>6</sup>	= 16.747 Atk
	1 PU	= 1.118 3 Ns <sup>2</sup> /m <sup>6</sup>		= 0.894 2 PU
Airway specific resistance	1 in wg			
	per 10 000 ft <sup>3</sup> /min	= 22.366 Ns <sup>2</sup> /m <sup>6</sup>	1 Ns <sup>2</sup> /m <sup>6</sup>	= 0.044 7 per 10 000 ft <sup>3</sup> /min
Density	1 lb/ft <sup>3</sup>	= 16.018 5 kg/m <sup>3</sup>	1 kg/m <sup>3</sup>	= 0.062 43 lb/ft <sup>3</sup>
	1 ton/yd <sup>3</sup>	= 1328.94 kg/m <sup>3</sup>		= 0.000 753 ton/yd <sup>3</sup>
Energy, work, heat	1 ft lbf	= 1.355 82 J	1 J	= 0.737 56 ft/lbf
	1 Btu	= 1055.06 J		= 0.000 948 Btu
	1 cal	= 4.186 8 J		= 0.238 89 cal
	1 therm	= 105.506 MJ		= 0.009 478 μtherm
	1 kWh	= 3.6 MJ		= 0.000 278 Wh
Power	1 hp	= 745.700 W	1 W	= 0.001 341 hp
Heatflow	1 ft lbf/min	= 0.022 6 W		= 44.254 ft lbf/min
	1 Btu/min	= 17.584 W		= 0.056 87 Btu/min
	1 RT	= 3517 W		= 0.000 2843 RT
	{ Refrigeration } ton			
Specific energy, Calorific value	1 ft lbf/lb	= 2.989 J/kg	1 J/kg	= 0.3345 ft lbf/lb
	1 Btu/lb	= 2326 J/kg		= 0.000 43 Btu/lb
	1 therm/ton	= 0.103 8 MJ/kg		= 9.634 μtherm/ton
Gas constants, Specific heat, Specific entropy	1 $\frac{\text{ft lbf}}{\text{lb } ^\circ\text{R}}$	= 5.380 3 J/kg K	1 J/kg K	= 0.185 9 $\frac{\text{ft lbf}}{\text{lb } ^\circ\text{R}}$
	1 $\frac{\text{Btu}}{\text{lb } ^\circ\text{R}}$	= 4186.8 J/kg K		= 0.000 2388 $\frac{\text{Btu}}{\text{lb } ^\circ\text{R}}$
Specific volume	1 ft <sup>3</sup> /lb	= 0.062 43 m <sup>3</sup> /kg	1 m <sup>3</sup> /kg	= 16.018 ft <sup>3</sup> /lb
	1 ft <sup>3</sup> /ton	= 0.027 87 m <sup>3</sup> /t	1 m <sup>3</sup> /t	= 35.881 ft <sup>3</sup> /ton

\* based on the Imperial Gallon  
where 1 U.S. gallon = 0.83 Imperial Gallons

APPENDIX I (Continued)

Note: 1 metric tonne (t) = 1 000 kg = 0.984 207 ton.

Dynamic viscosity	1 lb/fts	=	1.488 16	Ns/m <sup>2</sup>	1 Ns/m <sup>2</sup>	=	0.671 97	lb/fts
	1 poise	=	0.1	Ns/m <sup>2</sup>		=	10	poise
Kinematic viscosity	1 ft <sup>2</sup> /s	=	0.092 903	m <sup>2</sup> /s	1 m <sup>2</sup> /s	=	10.763 9	ft <sup>2</sup> /s
	1 stokes	=	0.000 1	m <sup>2</sup> /s		=	10 000	stokes
Thermal conductivity	1 Btu ft	=	1.730 73	$\frac{\text{Jm}}{\text{m}^2 \text{ s K}}$	1 $\frac{\text{Jm}}{\text{m}^2 \text{ s K}}$	=	0.577 79	$\frac{\text{Btu ft}}{\text{ft}^2 \text{ h } ^\circ\text{R}}$
	$\frac{\text{ft}^2 \text{ h } ^\circ\text{R}}$							
Thermal gradient	1 °F/ft	=	1.822 7	°C/m	1 °C/m	=	0.548 6	°F/ft
Moisture content	1 lb/lb	=	1	kg/kg	1 kg/kg	=	1	lb/lb
	1 gr/lb	=	0.000 1429	kg/kg		=	7 000	gr/lb
Temperature	K	=	°C + 273.15					
	°R	=	°F + 459.67					

For differential temperatures, 1 Centigrade degree = 1.8 Fahrenheit degrees.

For actual temperatures,  $1.8 \times t(^{\circ}\text{C}) + 32 = ^{\circ}\text{F}$ .

and  $\frac{t(^{\circ}\text{F}) - 32}{1.8} = ^{\circ}\text{C}$