UNIVERSITY OF THE WITWATERSRAND
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ENVIRONMENTAL ASPECTS IN TRACKLESS MECHANISED MINING

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ENVIRONMENTAL ASPECTS IN TRACKLESS MECHANISED MINING METHODS.

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A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in the partial fulfilment of the requirement for the Degree of Master of Science in Engineering

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I declare that this project report is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any Degree or Examination in any other University.

H J FOURIE

30th day of April 1991

I dedicate this work to my wife Ansie and our children Wouter, Wiehahn and Jana for all their love and patience during the past months.

TO GOD BE ALL THE GLORY

ENVIRONMENTAL ASPECTS IN TRACKLESS MECHANISED MINING METHODS - (TMMM)

ABSTRACT

The impact of TMMM on Environmental Engineering is pervasive in all aspects.

More critical aspects have been evaluated to quantify their impact on air and refrigeration of a typical deep, hot gold mine.

Heat load factors of diesel machines have been expressed by various authorities. Based on theory and multiple influences, these factors vary from 0,5 to 10 kilowatts of heat per kilowatt of rated diesel power. The efficiency or effective utilization of available power as related to rock extraction is poor. Research shows that the heat load factor is 1,475 times the rated power. Substituting diesel power with electrical equivalents can reduce both heat/refrigeration and air demands in Environmental Control. These factors are expressed in **chapter one.**

Knowing the impact of the above, methods of ventilation of the various TMMM's can be defined. A model has subsequently been developed for use in the **COMRO's** program on Environmental Engineering **(ENVIRON)**. Heat load graphs were constructed for future planning of the various mining methods.

Turning to the man that operates the equipment, two areas of concern are evaluated. **Firstly,** it has been determined that the metabolic work rate on operators are moderate without considering external harsh environmental conditions. Metabolic work rate vary between 180 and 214 W/m2. **Secondly,** tha heat stress on operators have been evaluated in a hot environment. Though the metabolic work rate is moderate, the accumulative effect of radiant heat from the machine and the surrounding ambient air puts the operator in the near hard work rate category. Measures have been proposed to reduce the effect of radiant heat in the driver's cabin where vehicle wall temperatures reaches up to 75°C. The specific cooling power of the air varies between 138 and 283 W/m2. This can be largely attributed to the gap between the wet and drybulb air temperatures of up to 9°C. These are expressed in **chapter two.**

Investigated in lesser detail are the controls installed to reduce the air pollution effect of gas emission from dieselised vehicles. Catalytic fume purifiers are installed to reduce the levels of exhaust gas emissions. The problem experienced is mainly the low exhaust gas temperatures (< 250°C) for the non-production vehicles. This result in high exhaust backpressure due to a lack of regeneration capabilities of the catalytic fume purifiers. Overall efficiencies of purifiers ranges between 43 and 64%.

In general, other areas that were also considered are listed below :

Methods of ventilating the various TMMM projects show an effective air factor for planning purposes of between 3,0 and 3,6 kg/s per kilotonne of rock broken per month.

Noise levels of vehicle operators were measured as an equivalent noise dose. Research shows that exposure to high levels of noise can lead to hearing impairment. Noise levels measured in the TMMM projects reveals high noise exposure in the lower frequency ranges. Equivalent noise levels range between 98 and 115 dBA. It is therefore necessary to suppress the noise at source or supply hearing protection to the operators. The problem is that no acceptable hearing protection device exists for use in hot environments. Side effects of high noise levels are hypertension and aggresiveness.

Economical air factors to ventilate areas where TMMM is introduced vary considerably and need to be investigated in more detail.

The geographical location in relation to the critical thermal level in the underground environment is of utmost importance. Air requirements to satisfy both contaminant dilution and heat removal aspects have been calculated to vary over a wide range. Economical airspeed in roadways and tunnels is influenced by the high excavation cost using TMMM.

Lastly, the development and introduction of jet fan technology was undertaken. This is an unexplored area for possible future research in TMMM. The financial benefits of using jet fans in drifts advanced to some 60 metres from the point of through ventilation is self evident.

Further work concerning fire prevention, escape strategies and dust suppression methods in TMMM must be done.

The development of a custom planning model is visualised for the future - using the results of the above work.

ACKNOWLEDGEMENT

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Chapter 1 :

Heatload Factors for Diesel Engines

1.1 PROBLEM

The low thermal eficiancy of the diesel internal combustion engine has a marked influence on the underground environment. The advantages in manuevarability of a diesel powered mining vehicle (to the mining fraternity over that of an electrically driven unit is evidant. The low thermal eficiency of the diesel engine play a major role in the cost of a trackless mining project when considering refrigeration or the hot underground air.

Difference in altitude and temperature between surface and underground adds an additional burden on the power output of a diesel engine. This relationship can be expressed mathematically as follows. The correction factor (kd), barometric pressure (p) and ambient temperature (t) relates as :

$$kd = (87{,}0 / p)^{0{,}65} * ((t + 273) / 298)^{0{,}5}$$

and

flywheel power on location as derated kilowatt (Kw rated * kd). The derating amounts to some 10,6% on the flywheel power Falk (1988:50).

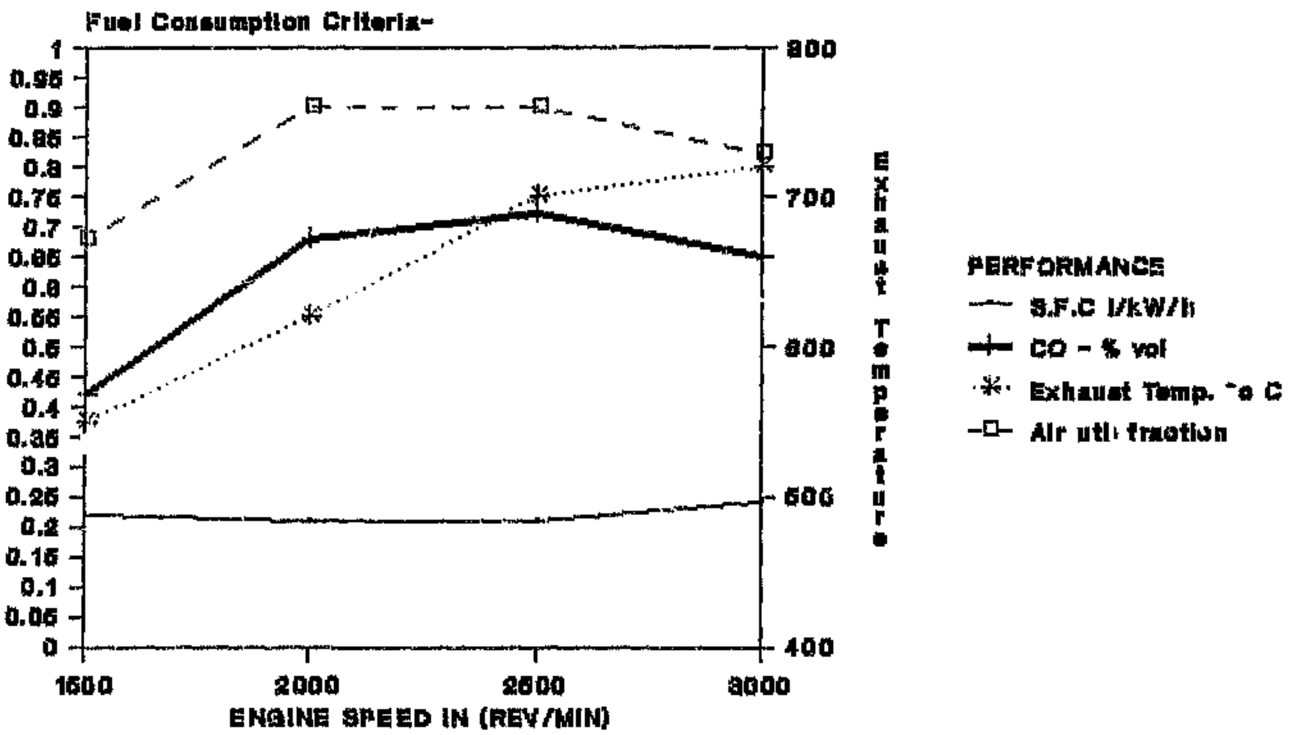
The further complicating factor of negotiating slopes of up to 14° whilst travelling uproadways, adds to heat generated by these machines. Planning the required fleet for a specific payload is standard practice and the factor for calculating the total power required is known for various mining methods.

The problem lies in finding the peak heat load period in any trackless mining project. This peak heat load is that phase when the hauling of rock is at its peak. It is important to find the utilization of the various machines, taking into account the availability of the units, the full power period, distance and slope factors and engine condition Fourie (1989:45).

Figure 1.1 show such a typical cycle for a load haul dumper in respect of the exhaust gas temperatues.

figure 1.1 - Expanded time temperature variation for load cycle Falk (1988:112).

PERFORMANCE OF INDIRECT INJECTION ENGINE VARIATION OF CRITERIA IN RELATION TO ENGINE SPEED



SFC = Specific Fuel Consumption FIG 1.1

The refrigeration requirements for a project are calculated on the peak heat load period. Gross inaccuracies occur if an average figure is used for refrigeration requirement calculation.

Figure 1.2 relates the problem of heat load over a 24 hour period.

figure 1.2 - Detailed time temperature traces Dainty (1985:363)

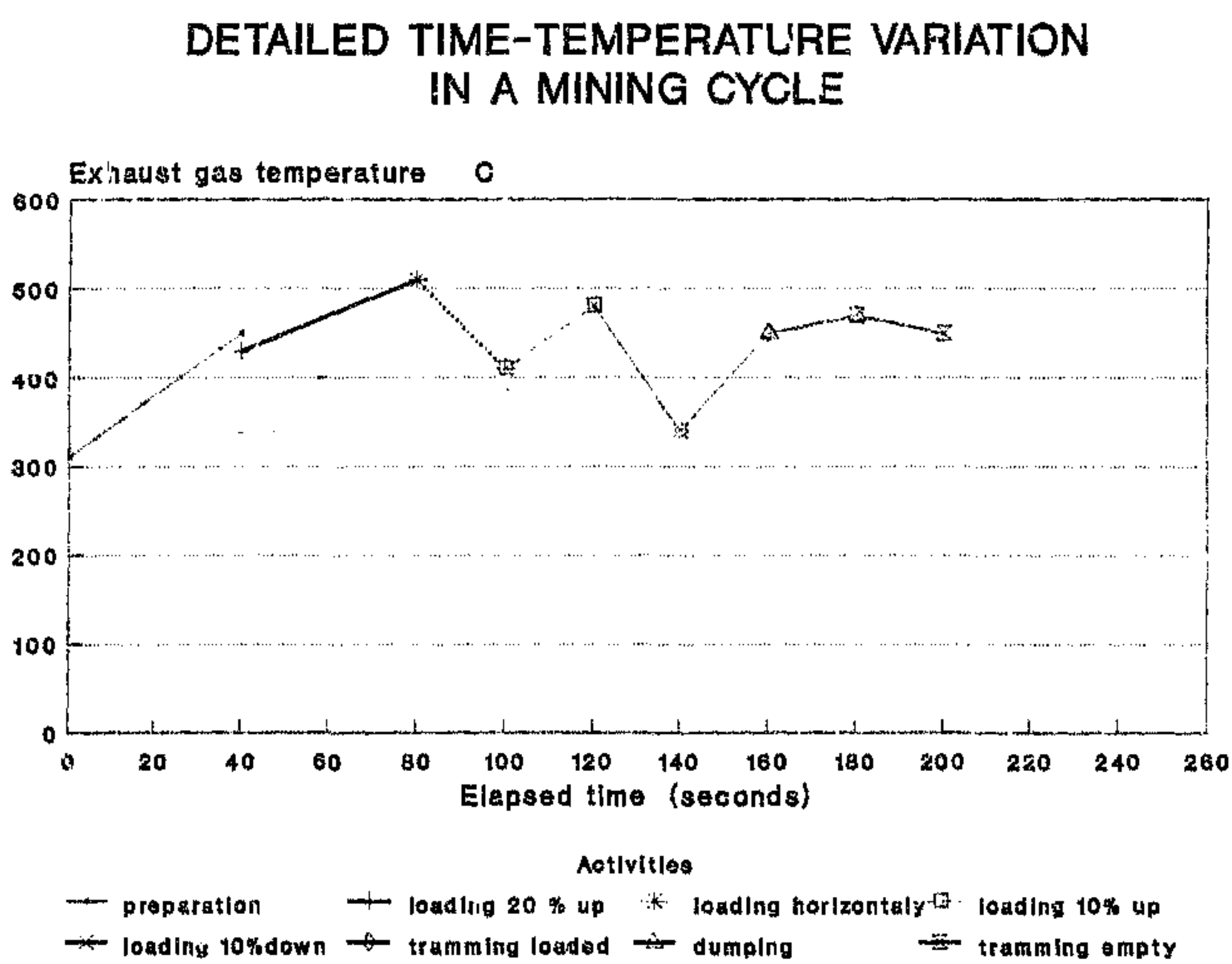

DETAILED TIME-TEMPERATURE VARIATION
IN A MINING CYCLE
Exhaust gas temperature C
600
500
400
300
200
100
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260
Elapsed time (seconds)
Activities
preparation
loading 20 % up
loading horizontaly
loading 10% up
loading 10%down
tramming loaded
dumping
tramming empty

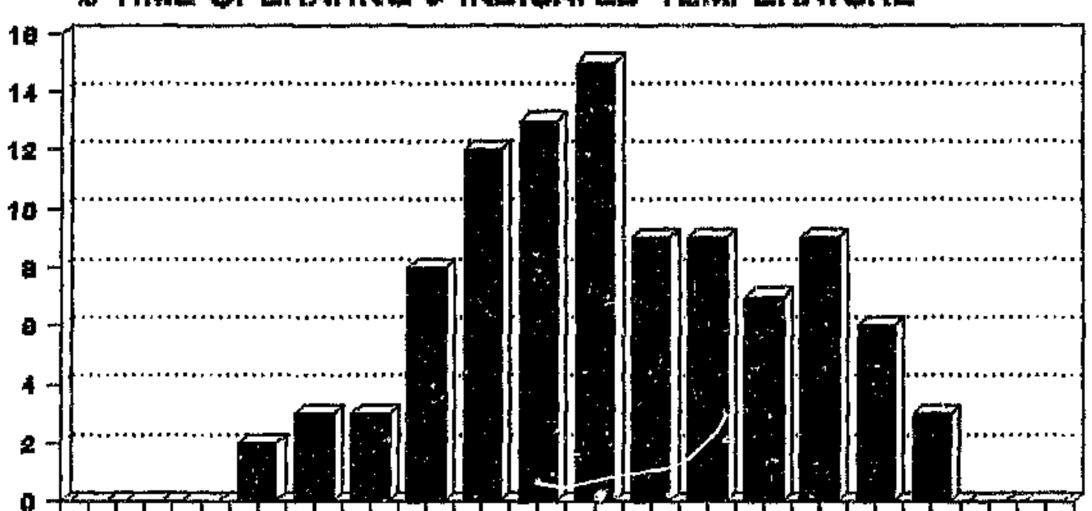
FIG 1.2

It is important to note that the necessary temperature histograms are required to determine the frequency in which the diesel powered vehicles operate in the various temperature ranges. Figure 1.3 has been taken from work done to determine the exhaust gas temperature for catalytic gas purifiers regeneration. This is however also appropriate when discussing heat load in TMMM projects - in order to calculate the required refrigeration.

figure 1.3 - Temperature histogram - ST6C scoop with a Deutz F8L 714

TEMPERATURE HISTOGRAM - ST 6C
LHD WITH A DEUTZ 164 kW F8L714 ENGINE

% TIME OPERATING @ INDICATED TEMPERATURE



	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540
FREQUENCY %	0	0	0	2	3	3	8	12	13	15	9	9	7	9	6	3	0	0

EXHAUST TEMPERATURE ^o CELSIUS

EXHAUST TEMPERATURE
FREQUENCY %

FIG 1.3

Gross variations occur from vehicle to vehicle and in some instances temperature variations at the engine between exhaust ports vary up to 100°C.

It is therefore necessary to find some other means of determining a project heat load.

1.2 LITERATURE SURVEY

Evaluation of the performance curves of the vehicle manufacturers indicate that the variation of altitude and ambient temperature has an influence on the performance of the diesel engine (as indicated previously).

During the initial planning of the TMMM projects, figures were obtained, based on the equipment requirements of the various departments. The figures required for refrigeration requirement calculations had one drawback - actual utilization figures were not available.

Due to the diesel machine's thermal eficiency, heat production is three times the actual rated power McPherson (1984:241).

Fourie (1986:57) calculated the diesel rated power required per kilotonne of rock handled per month as 37 kW. The fuel consumption amounted to 0,51 l/tonne of rock broken per month. The effective full power utilization was only 19 % per day or 26 % during the peak loading shift. The calculation involved some 38 vehicles over an 8 month period.

Based on the above, the heat load factor is 1,475 kW heat per kW of rated diesel power and hence 54,5 kW heat per kilotonne of rock handled. These figures will now be compared with the latest data collated for the period 1989 and 1990.

Unsted (1989:38) reflects figures of 1,88 kW heat/kW rated diesel power for low emission diesel on average. The promising correlation of 0,545 to 0,670 litres per ton of rock broken has been reached by the above. Unsted has calculated these figures during a special project on another mine with similar conditions to that of this research project. The disadvantage is that only one unit had been checked during the research period. The heat load figure varied between 1,1 and 3,4 kW of heat/kW rated power for idling and peak load respectively.

Burgwinkel (1985:625) shows a figure of 2,78 kW heat/kW rated power for a diesel locomotive. The problem of comparing Burgwinkel's data with that of a gold mine lies in the terrain chosen for testing the unit. The slope of the travelling ways vary between 0,5 and 9,0 degrees.

Middleton (1989:244) did a study as member of the Chamber of Mines Research Organisation (COMRO) involving locomotives and LHD's. These findings relate the heat from locomotives as 1,5 times the rated power. On the TMMM side, a Jarvis Clark JS 220 (102 kW rated engine power), generated 2,2 times more heat than the rated power based on fuel consumption. Again the test was only conducted on one machine for both the conventional and trackless project.

McPherson (1984:204) express the heat load from dieselised vehicles as 2,83 times the kW of useful work at full load. This figure calculated from data collected in the United Kingdom and the United States of America coal mines. The fuel consumption in this case is 0,3 l of fuel/hour per rated kW. The problem in each case is at what fraction of the shift do these machines operate under full load conditions ?

Fourie (1989:45) shows the following factors to be used to calculate heat flows/refrigeration requirements.

Temperature dependent heat sources (i.e. factors that include heat flow from rock and fissure water primarily) are shown in table 1.1

Refer to appendix A - E (page 81) for an explaination of the mining methods.

Cut and fill mining	= 0,938
Vertical crater retreat	= 0,415
Narrow reef stoping	= 2,143
Development ends	= 2,286

Table 1.1 - Mining Method kWheat/ktonne Rock Broken/°C VRT (Temperature dependent)

Temperature independent heat sources indicate basically all artificial sources such as equipment.

Mining Method	kW heat/kton Rock Broken per Month	
Cut and fill	Diesel	42,8
	Electric	32,5
Vertical Crater Retreat	Diesel	14,8
	Electric	41,5
Narrow Reef	Diesel	37,0
	Electric	79,4
Development	Diesel	37,0
	Electric	32,5

Table 1.2 - Heat generated in different mining areas

These figures include the 1,475 kW heat per kW rated diesel power and 0,75 kW heat per kW rated electrical power as utilization figures and incorporates the thermal deficiency of the diesel units.

The basis of the above figures were gathered from evaluation done for some 16 TMMM projects. The heat loads were calculated using the COMRO computer program "HEAT" - with the addition of the data from the 1986 study on fuel consumption.
A summary of the design parameters are given in table 3 involving the work done by McPherson, Fourie and Unsted.

Source	kW heat/ kW rated	Cal Value kJ/l	Fuel used l/ton	l Fuel/ hour per rated kW	Heat MJ/ton
McPherson	2,83	34 000		0,30	
Fourie	1,475	36 538	0,545	0,51	20,07
Unsted :					
LED fuel	1,88	38 273	0,67	0,19	19,0
LOCO fuel	2,10	37 528	0,89	0,21	24,8
Surface fuel	1,71	38 377	0,71	0,17	20,2

Table 1.3 - Summary of planning figures

In the case of McPherson and Fourie, US diesel fuel and LED (low emmmission diesel)fuel was used respectively. LOCO fuel is diesel fuel marketed specificaly for use in locomotives in the gold mines.

This correlation is good. The data collated was taken over a very short period of time and did not simulate a representative sample. Also that the work does not take into account tha various mining methods employed in TMMM. Lastly, the gold mining industry has progressed significantly along the learning curve to improve the productivity and availability of diesel powered vehicles over the past five years.
It is for this reason that it is necessary to recalculate the fuel consumption figures for use in future project planning.

1.3 OVERVIEW OF THE THEORETICAL SOLUTION

To overcome the heat load problem, it is necessary to determine the peak heat load period using the fuel consumption figures. It will be shown, from the production data, that the peak "hauling of rock" period is during two short 4 hour periods during the afternoon and night shifts. It can therefore be said that the peak heat flow period occurs on 33% of the day. The supply of refrigeration during this period is crucial to any machine to operate satisfactorily and to the operator thereof.

The Solution is two fold :

i) Calculate the heat load figures from data collated over the past 24 months in some 4 projects. The data to include planned and actual rock hauling performance, fuel consumption, derated diesel power, fuel type used and hours of operation in specific period.

Check the hauling split over the day of work.

The performance calculated to show actual diesel power used per ton of rock broken, fuel consumption per kW diesel rated power and per ton rock broken. Based on the above, the percentage full power utilization per machine to be calculated.

Finally, the peak heat load figures will be known based on fuel consumption.

Heat = fuel consumption x combustion efficiency x calorific value.

Where : fuel consumption is expressed per unit time in the high production period (litres/second).

- Combustion efficiency is assumed at an average of 95%.
- Calorific value of diesel fuel used by the group = 36 538 kJ/l.

This figure can then be used to express machine utilisation at full load by quoting the heat generation by the fleet of vehicles, based on the fuel consumption as a ratio of the maximum possible heat (power) generation by the fleet, during the same period of time.

ii) This empirical data will then be checked and verified against other sources.

The above results were processed by the COMRO 'ENVIRON' program and figures derived for the various TMMM projects taking into account the temperature dependent and independent heatflow figures. This program was developed by Von Glen (1987).

Heat from diesel engines was then expressed as rated diesel power required per tonne of rock broken per month, multiplied by the heat generated per kilowatt of rated diesel power. This heat generation factor to include all aspects such as down time, fuel calorific value and utilisation of machinery over a 24 hour period. The fuel calorific needs to be known.

1.4 PRACTICAL EVALUATION AND RESULTS

1.4.1 Diesel vehicle fleet

The vehicle fleet are shown per project in tables 4 - 7. In summary the total fleet consisted of 56 vehicles amounting to 4803 kW rated diesel power.
Note that the term "power deration based on gas emmissions" mean "smoke and nitrous oxide limiting" power output in the tables 1.4 to 1.7 .

Code No	Prod Grp	Description	Manufact	Model	Spec	kW Rate	Cyl	Power* Derated	Total No.	POWd
LW 1	LHD	Wagner LHD	HV Dav	3.5T	3.5m3	144.00	8.00	134.35	2.00	269
LW 2	LHD	Wagner LHD	HV Dav	60	6.0m3	180.00	10.00	167.94	1.00	168
GH 5	LHD	GHH LHD	IMG Eng	LF12	8.0m3	216.00	12.00	201.53	0.00	0
										437
TW 1	Truck	Wagn D/Truck	HV Dav	08	18Ton	190.00	10.00	167.94	0.00	0
UW 2	Util	Wagn U/Veh	HV Dav	UT45A	SC198L	63.00	6.00	58.78	3.00	176
UN 1	Util	VT Veh	Normet	PK1000		63.00	6.00	58.78	0.00	0
UY1/US1	Util	SVM3000	Spec Veh	SVM3000	Jeep	32.00	3.00	29.86	0.00	0
UG 1	Util	Scaler	JI Case	580G	Scaler	50.00	4.00	46.45	2.00	93
EW 1	Util	Lub Cassette	HV Dav	000	Util	63.00	6.00	58.78	0.00	0
Case	Util	Grader	Case		Grader	50.00	4.00	46.65	0.00	0
										270
RE 1	Rigs	Secoma/ R/Bolt	Eimco Sec	Rig	D/Rig	63.00	6.00	58.78	0.00	0
DA 1	Rigs	Boomer D/Rig	A/Copco			52.00	5.00	48.52	2.00	97
DF 2	Rigs	Single Boom	Seco	Rig	D/Rig	52.00	5.00	48.52	0.00	0
										97
						TOTAL POWER DERATED = kW				803

* = Power deration based on gas emmissions
- not done underground as at yet.

The temperature and elevation used correspond to that of the project to be analysed.
TEMPERATURE AVERAGE = 29.5/38.5°C
BAR PRESSURE = 100.5

Table 1.4 - 58 Level TMMM vehicle fleet

Code No	Prod Grp	Description	Manufact	Model	Spec	kW Rate	Cyl	Power* Derated	Total No.	POWd
LW 1	LHD	Wagner LHD	HV Dav	3.5T	3.5m3	144.00	8.00	131.29	2.00	263
LW 2	LHD	Wagner LHD	HV Dav	6C	6.0m3	180.00	10.00	164.11	2.00	328
GH 5	LHD	GHH LHD	IMG Eng	LF12	8.0m3	216.00	12.00	196.93	1.00	197
										788
TW 1	Truck	Wagn D/Truck	HV Dav	08	18Ton	190.00	10.00	164.11	0.00	0
UW 2	Util	Wagn U/Veh	HV Dav	UT45A	SC198L	63.00	6.00	57.44	2.00	115
UN 1	Util	VT Veh	Normat	PK1000		63.00	6.00	57.44	0.00	0
UY1/US1	Util	SVM3000	Spec Veh	SVM3000	Jeep	32.00	3.00	29.18	0.00	0
UG 1	Util	Scaler	JI Case	580G	Scaler	50.00	4.00	46.59	3.00	137
EW 1	Util	Lub Cassette	HV Dav	000	Util	63.00	6.00	57.44	0.00	0
Case	Util	Grader	Case		Grader	50.00	4.00	45.59	0.00	0
										252
RE 1	Rigs	Secoma/ R/Bolt	Eimco Sec	Rig	D/Rig	63.00	6.00	57.44	0.00	0
DA 1	Rigs	Boomer D/Rig	A/Copco	Rig	D/Rig	52.00	5.00	47.41	2.00	95
DF 2	Rigs	Single Boom	Seco	Rig	D/Rig	52.00	5.00	47.41	0.00	0
										95
						TOTAL POWER DERATED = kW				134

* = Power deration based maximum gas emmission - not done as at yet.

The temperature and elevation used correspond to that of the project to be analysed.
TEMPERATURE AVERAGE = 29.5/38.5°C
BAR PRESSURE = 103.5

Table 1.5 - 70 Level TMMM vehicle fleet

Code No	Prod Grp	Description	Manufact	Model	Spec	kW Rate	Cyl	Power* Derated	Total No.	POWd
LW 1	LHD	Wagner LHD	HV Dav	3.5T	3.5m3	144.00	8.00	132.48	1.00	132
LW 2	LHD	Wagner LHD	HV Dav	6C	6.0m3	180.00	10.00	165.60	1.00	166
GH 5	LHD	GHH LHD	IMG Eng	LF12	8.0m3	216.00	12.00	198.72	0.00	0
										298
TW 1	Truck	Wagn D/Truck	HV Dav	DB	18Ton	190.00	10.00	165.60	0.00	0
UW 2	Util	Wagn U/Veh	HV Dav	UT45A	SC198L	63.00	6.00	57.96	2.00	116
UN 1	Util	VT Veh	Normat	PK1000		63.00	6.00	57.96	0.00	0
UY1/US1	Util	SVM3000	Spec Veh	SVM3000	Jeep	32.00	3.00	29.44	0.00	0
UG 1	Util	Scaler	JI Case	580G	Scaler	50.00	4.00	46.00	0.00	0
EW 1	Util	Lub Cassette	HV Dav	000	Util	63.00	6.00	57.96	0.00	0
Case	Util	Grader	Case		Grader	50.00	4.00	46.00	0.00	0
										252
RE 1	Rigs	Secoma/ R/Bolt	Eimco Sec	Rig	D/Rig	63.00	6.00	57.96	0.00	0
DA 1	Rigs	Bcomer	DA/Copco	Rig	D/Rig	52.00	5.00	47.84	1.00	48
DF 2	Rigs	Single Boom	B/Seco	Rig	D/Rig	52.00	5.00	47.84	0.00	0
										48
						TOTAL POWER DERATED = kW				462

* = Power deration based maximum exhaust gas emmission not done underground as at yet.
The temperature and elevation used correspond to that of the project to be analysed.
TEMPERATURE AVERAGE = 29.5/38.5°C
BAR PRESSURE = 102.5

<u>Table 1.6 - 65-2W TMMM vehicle fleet</u>

Code No	Prod Grp	Description	Manufact	Model	Spec	kW Rate	Cyl	Power* Derated	Total No.	POWd
LW 1	LHD	Wagner LHD	HV Dav	3.5T	3.5m3	144.00	8.00	127.68	3.00	383
LW 2	LHD	Wagner LHD	HV Dav	6C	6.0m3	180.00	10.00	159.60	3.00	479
GH 5	LHD	GHH LHD	IMG Eng	LF12	8.0m3	216.00	12.00	191.53	1.00	192
										1053
TW 1	Truck	Wagn D/Truck	HV Dav	DB	18Ton	180.00	10.00	159.60	3.00	479
UW 2	Util	Wagn U/Veh	HV Dav	UT45A	SC198L	63.00	6.00	55.86	3.00	168
UN 1	Util	VT Veh	Normat	PK1000		63.00	6.00	55.86	1.00	56
UY1/US1	Util	SVM3000	Spec Veh	SVM3000	Jeep	32.00	3.00	28.37	0.00	0
UG 1	Util	Scaler	JT Case	580G	Scaler	50.00	4.00	44.33	6.00	266
EW 1	Util	Lub Cassette	HV Dav	000	Util	63.00	6.00	55.86	1.00	56
Case	Util	Grader	Case		Grader	50.00	4.00	44.33	1.00	44
										590
RE 1	Rigs	Secoma/ R/Bolt	Eimco Sec	Rig	D/Rig	63.00	6.00	55.86	2.00	112
DA 1	Rigs	Boomer	DA/Copco	Rig	D/Rig	52.00	5.00	46.11	5.00	231
DF 2	Rigs	Single Boom	B/Seco	Rig	D/Rig	52.00	5.00	46.11	0.00	0
										342
						TOTAL POWER DERATED = kW				2464

* = Power deration based on maximum exhaust gas emmission not done underground as at yet.
The temperature and elevation used correspond to that of the project to be analysed.
TEMPERATURE AVERAGE = 29.5/38.5°C
BAR PRESSURE = 108.5

Table 1.7 - 85 Level TMMM vehicle fleet

1.4.2 Heat / Unit installed diesel power

The data collated from the Planned Maintenance Section of the Engineering Department, coupled with the information of production figures over the period March 1988 to March 1990 gives the following values. Details of these analysis is attached as Appendix F (page 86). In summary the results can be shown in Table 1.8.

Project	1/kW/h	kW der	Oper hrs	1/tonne	kW/kTonn	kWd/kTm	Mining Method
65-2W	0,01	462	20415	0,81	31,24	43,55	(a)
58 Lev	0,05	803	21376	1,01	39,12	61,10	(a)
85 Lev	0,01	2464	165193	0,57	21,81	62,12	(a - d)
70 Lev	0,015	1134	58309	0,44	17,07	30,11	
Weighted Average	0,0127	876	929711	0,682	27,31	49,22	
TOTALS		4803	295293				

Table 1.8 - Heat load parameters - TMMM - 1990/91

REMARKS

1. Previous analysis (1986) show

	Mining Method	kWd/kTonne/Month
a)	Cut & fill mining	42,87
b)	Vertical crater retreat	14,8
c)	Narrow reef stoping	37,0
d)	Development	37,0

Also "kW der" is kW derated power as per page 1 and "kWd" is kW diesel power.
Depending on the ratio of tons from the various mining methods - on equal distribution - this figure was 32,9 diesel rated power / kilotonne of rock broken per month compared to the 49,22 now calculated.

2. Fuel consumption : previous 0,51 l/tonne
now 0,682 l/tonne

3. Based on a calorific value of 38 500 kJ/l (and not 36 538 kJ/l, as in the past) the heat generation from diesel powered vehicles underground would therefore be 24,42 MJ/ton. This difference in calorific value can be attributed to the change in diesel fuel type used.

4.3 Heat / Unit tonne broken per month

The above figures can now be used in any one of the 'ENVIRON' heatflow simulations programmes. Figures shown under the literature survey material can now be updated. Temperature independent heat load factors are shown in Table 9.

Mining Method	kW Heat / kTon Rock Broken/m
Cut and fill	64,03
Vert crater retreat	22,02
Narrow reef	55,50
Development	55,50

Table 1.9 - Temperature Independent Heat Loads Corrected

5. **DISCUSSION**

Due to the difficulty of simulating a TMMM project in a heatflow project - the factors as in the above results can be used to predict heat loads in any project.

The typical simulations layout is shown in Appendix G (page 3). The results are presented in a graph and plotted against virgin rock temperature on the one hand and production on the other. Figures 1.4 - 1.6 show the final result of the work done - incorporating all the necessary data.

If more firm figures are available to predict / calculate heat loads in the TMMM then they must be used. However, global planning usually demands more rapid results on the total air and refrigeration requirements. It is for this reason that these graphs were generated.

Practice indicate that these figures are sufficiently accurate in predicting heat loads.

The use of electrically powered equipment is proposed from an environmental pollution point of view - on both economical and pollution grounds. The heat released by an electrical motor is 10% of the duty from an inefficiency of the motor and the 90% useful work is released as frictional heat. A Diesel engine is considered to release 1/3 of its energy as heat in the exhaust, 1/3 in heat transfer from the engine and radiator and 1/3 as work done which is eventualy released as heat to the environment. For an engine rated at R kW, the heat released as per Gunderson (1989:262) is:

Diesel R + 2R = 3R and

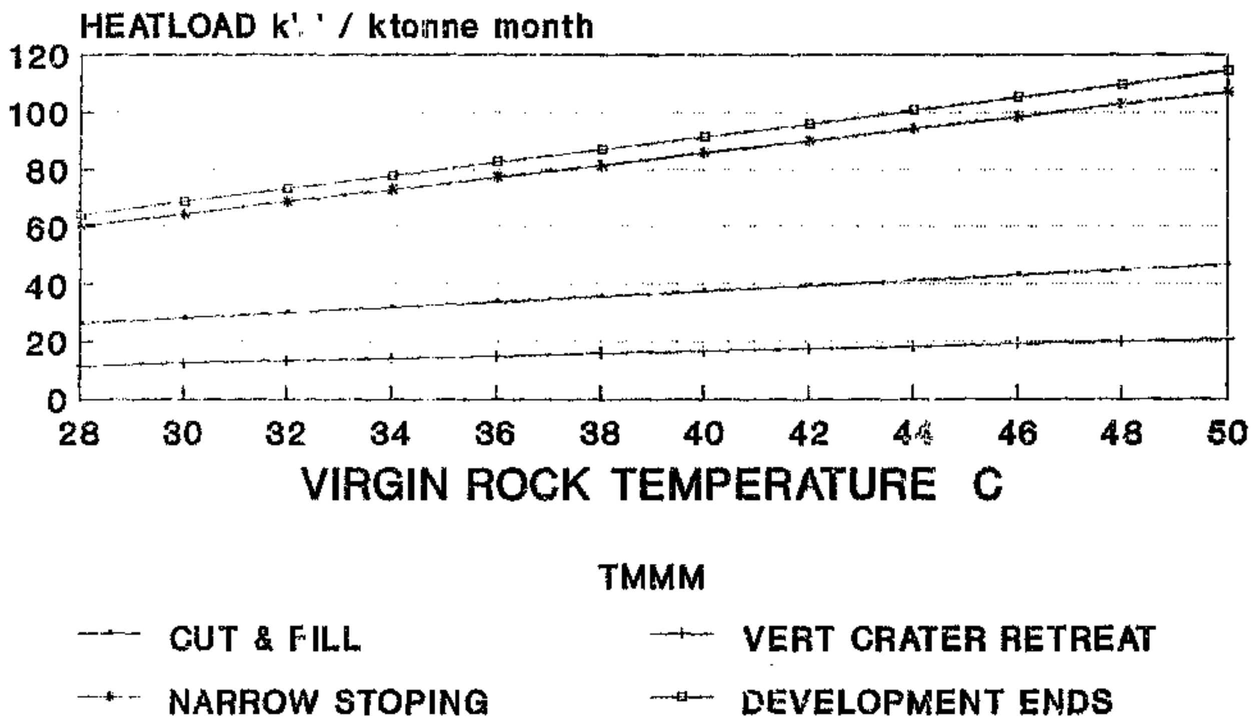
Electric R + 0,11R = 1,11R

The heat generation is therefore 3 times the heat from a equivalent electric motor. However, the work done by both machines is the same, even if this is converted to heat, The surplus heat liberated by a diesel engine is 20 times that of an electric machine (2R/0,1R).

Considering the cost of 1 kW of cooling equates to 0,7kW of electrical power - the cost of using electrical powered vehicles should be considered.

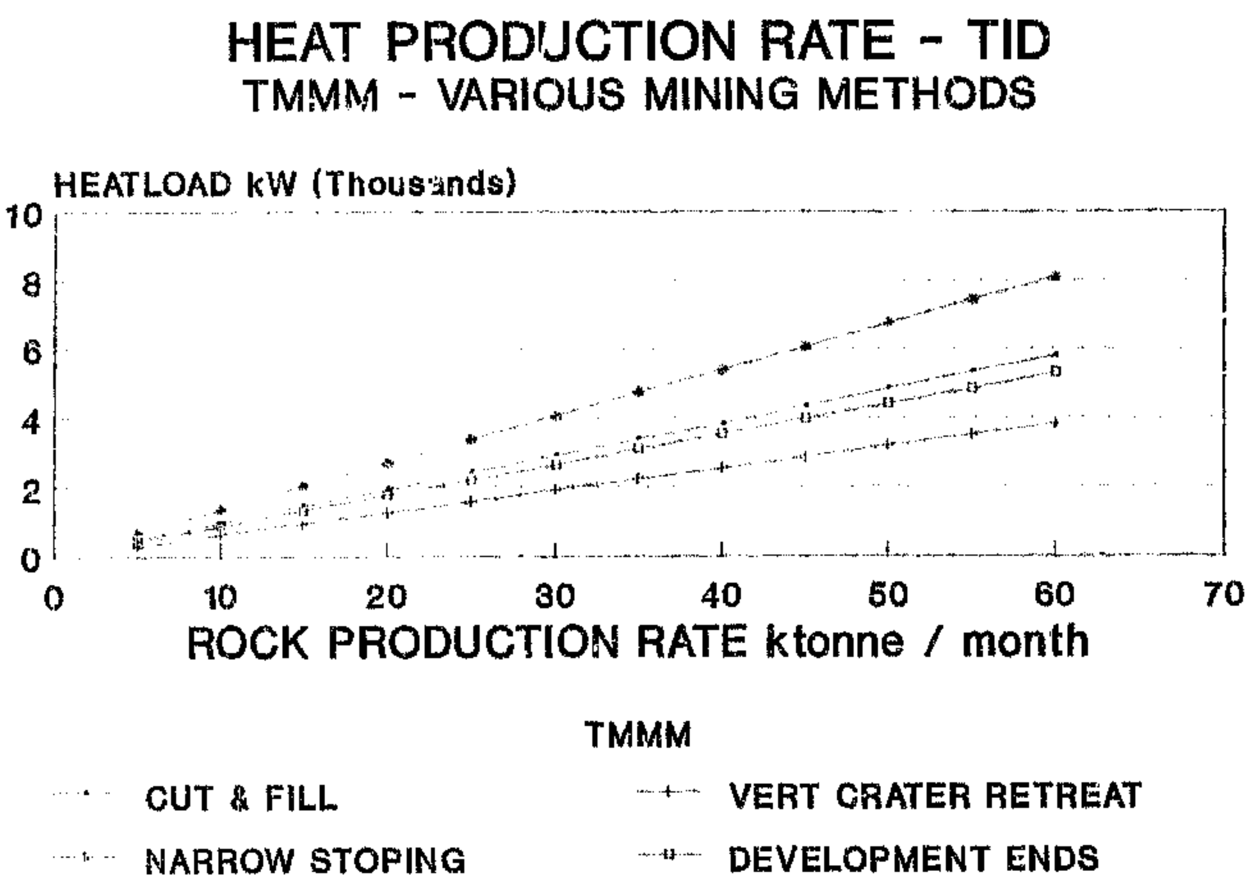
The second part of this research document looks at the effect of heat stress on the vehicle operator.

HEAT PRODUCTION RATE - TD
TMMM - VARIOUS MINING METHODS



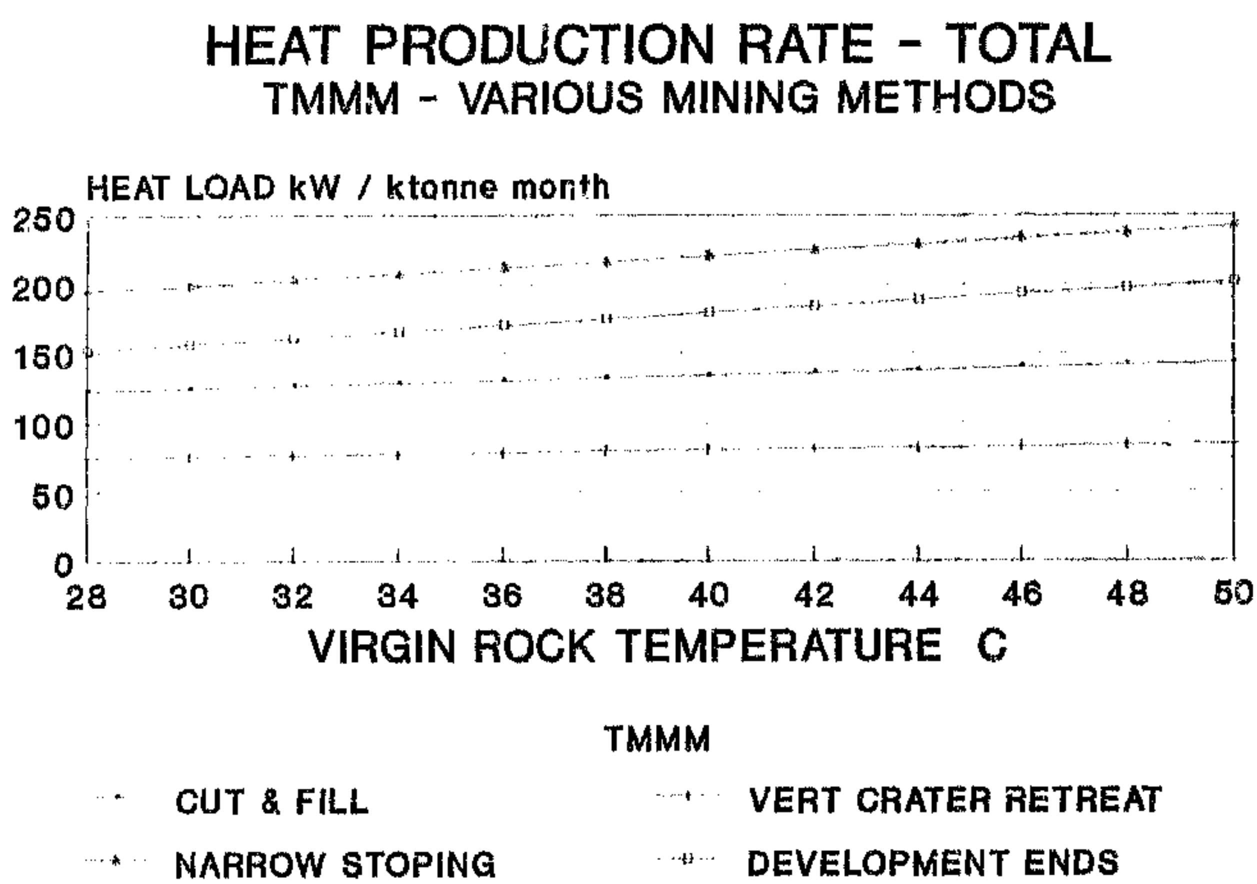
BASED ON ENVIRON HEAT FLOW SIMULATIONS
TD = TEMPERATURE DEPENDENT HEAT LOAD

 FIG 1.4



BASED ON ENVIRON HEAT FLOW SIMULATIONS
TID = TEMPERATURE INDEPENDENT HEAT LOAD

24 FIG 1.5



BASED ON ENVIRON HEAT FLOW SIMULATIONS
TOTAL = TID + TD HEAT LOAD FACTORS

FIG1.6

Chapter 2 :

Heat and Other Stress Factors on Machine Operators

1. PROBLEM

The heat generation by diesel powered vehicles underground has a major impact on the environment. As discussed in chapter 1, this generation is three times the rated power in theory.

It is necessary to calculate/investigate the heat stress to which the operators of these vehicles are exposed to. Heat stress can be defined as that fraction of heat by which specific cooling power of the air is less than the metabolic heat generated by the human body whilst performing a specific task in specific ambient conditions. This additional stress on the body results in an increase in the core temperature of the incumbent. This in turn can result in a deterioration of physiological and psychological performance of the driver.

The heat (energy) balance of the human body can be summarised as follows with all parameters expressed as heat generation per unit body area (W/m^2) :

Human bodyheat consists of :

(Metabolic energy production) minus (mechanical work done) minus (respiratory heat exchange) minus (heat storage in the body).

Cooling mechanisms of the body :

Radiant heat loss + convective heat loss + evaporative heat loss + conductive heat loss.

Specific cooling power of the air :

Is the ability of the air to accommodate the heat from the cooling mechanism of the body.

These factors have to date not been collated for vehicles operators

External factors :
Efficiencies and productivity of the diesel powered vehicles is largely dependent on the calibre of operator. However, the performance of the operator again is influenced by external factors impinging on his physiological abilities, which is further restrained by a poor ergonomically designed cabin. The external factors can be classified as:

- Extreme variations in the temperature spectrum. This spectrum includes the natural wetbulb, psychrometric wetbulb, drybulb temperature, black globe and differences between the wet and drybulb temperatures.

- The natural wetbulb temperature in this context means the reading obtained when a wetbulb thermometer is exposed to the natural airflow over the bulb. On the other hand, the psychrometric wetbulb temperature is taken when the wetbulb is exposed to a constant airspeed of 4,0 m/s.

- Drybulb temperatures which exceed 35°C makes policy decisions on the wear of clothing extremely difficult. Temperatures above this level, increase radiant heat above the evaporative heat removal capacity (EMAX). Also the evaporative barrier posed by the clothing increases the core temperature of the operator.

- Hancock, (1981:77), also showed that under higher effective temperatures of between 38,1 - 45,6°C definite impairment of mental performance occurs. Effective temperature is an index of environmental heat which synthesizes drybulb temperature, relative humidity and air movement. High effective temperatures also increases aggression of man towards the system.

Work done by Anderson (1989:76) show man's higher aggressive tendency towards the system during hot summer conditions at surface level. It is expected that this phenominon will also occur underground if cool and hot conditions are compared. Aggression in the form of mishandling the vehicle. Figure 2.1 show some data to proof this statement.

QUARTERLY & SEASONAL DISTRIBUTION OF AGGRESIVE BEHAVIOUR

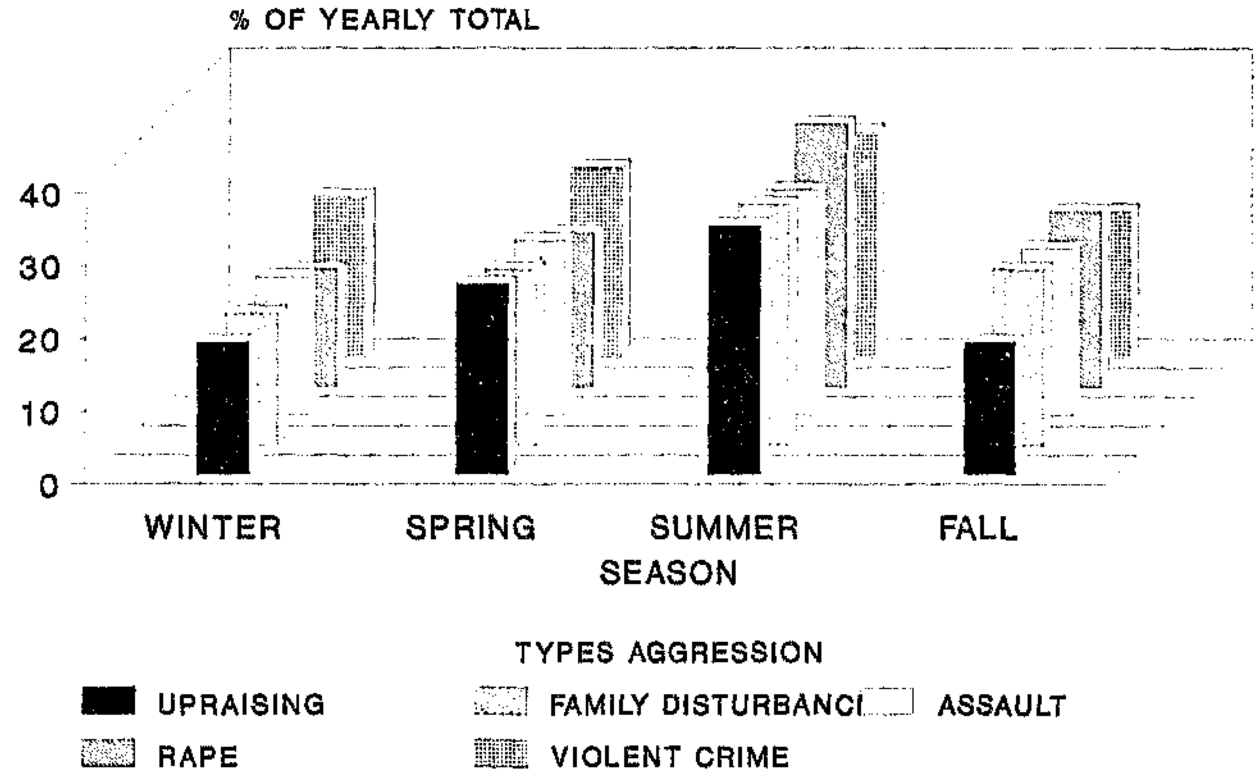


FIG 2.1 (7)

Ergonomic design :

- The driver's cabin of the diesel powered vehicles has an extremely poor ergonomic design. It plays a major role in the drivers ability to handle and control the vehicle effectively. These include:

  - Vision and visibility in the work situation
  - Illumination of the surroundings
  - Lack of radiant heat shielding or at least the reduction of emissivity, as the vehicle wall temperature in the driver's cabin is as high as 65°C.
  - Seat design and associated spinal discomfort
  - Reduced motor function of the legs due to the position of foot controls
  - Noise exposure due to a lack of attenuation facilities (between 90 - 120 dBA equivalent level).
  - Position of the cabin in relation to the engine. The heat removed from the engine should be discharged away from the driver.

- Duration of the work period, the frequency of and length of rest pauses has a marked impact on the overall capabilities of the operators. Drivers spend some 7 - 8 hours on the machine - sometimes without any rest period.

- Relative air speed plays a major role in all the heat stress indices and the lack thereof in the cabin affects the cooling power of the air. Especialy when travelling in the same direction as the natural airstream in the excavation.

Acclimatization and general fitness of the worker:

There has been no scientific evaluation of the vehicle operators concerning heat stress. Classification has been done based on their physical activity, by which they are classed in the light work category (115,0 W/m^2). See the relation of these operators to that in the other work categories in table 2.1 .

Light work <115 W/m2	Moderata work >115 <180 W/m2	Hard work >180 <240 W/m2
Winch operator Sweeper Drill assistant	Operating box front Drilling Barring	Hand tramming Shovelling Timber transport in stopes
Walking	Building matt packs Team leaders	
Drain cleaning	Vehicle operators ?	

Table 2.1 - Classification of mining tasks according to metabolic heat production for use in the assessment of heat stress

No work has been done on the external influences (ambient conditions) impact on the classification of heat stress of drivers.

Impaired concentration during work period and its influence on the driver.

Acclimatisation of the existing conventional work category people are done under conditions where the specific cooling power of the air does not exceed 200W/m^2.

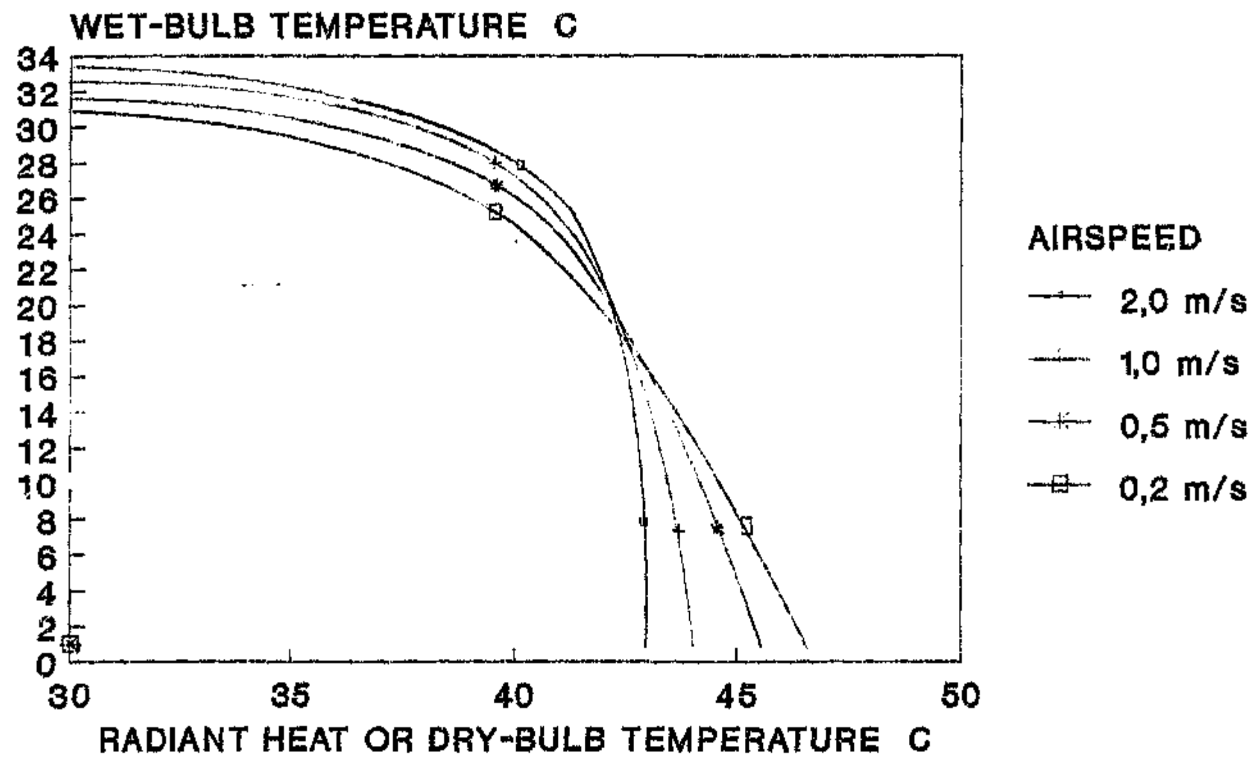
The effect of radiant heat is neglected and the gap between the wet and drybulb is kept between 2,0 and 2,5°C.

Gaps of up to 10°C are experienced by vehicle operators. It is therefore necessary to evaluate the metabolic work rate and the specific cooling power of the air in order to determine the heat stress of the operators.

It is for the above reasons that some research is required into the heat stress of operators of diesel powered vehicles. Figure 2.2 show the relation between psychrometric wetbulb temperature, radiant or drybulb temperature and windspeed to indicate the deminishing importance of this wetbulb temperature in hot dry conditions. (Stewart 1984:551).

Figures 2.2 to 2.4 have been included to show that the relevant factors have an impact on the specific cooling power of the air surrounding the vehicle operator.

DEMINISHED IMPORTANCE OF WETBULB TEMPERATURE IN HOT-DRY CONDITIONS



moderate work(180 W/m^2),ta=tr,P=100KPa
sweat rate= 0,46kg/m^2h
mean skin temperature=35,1 ^o C fig 2.2

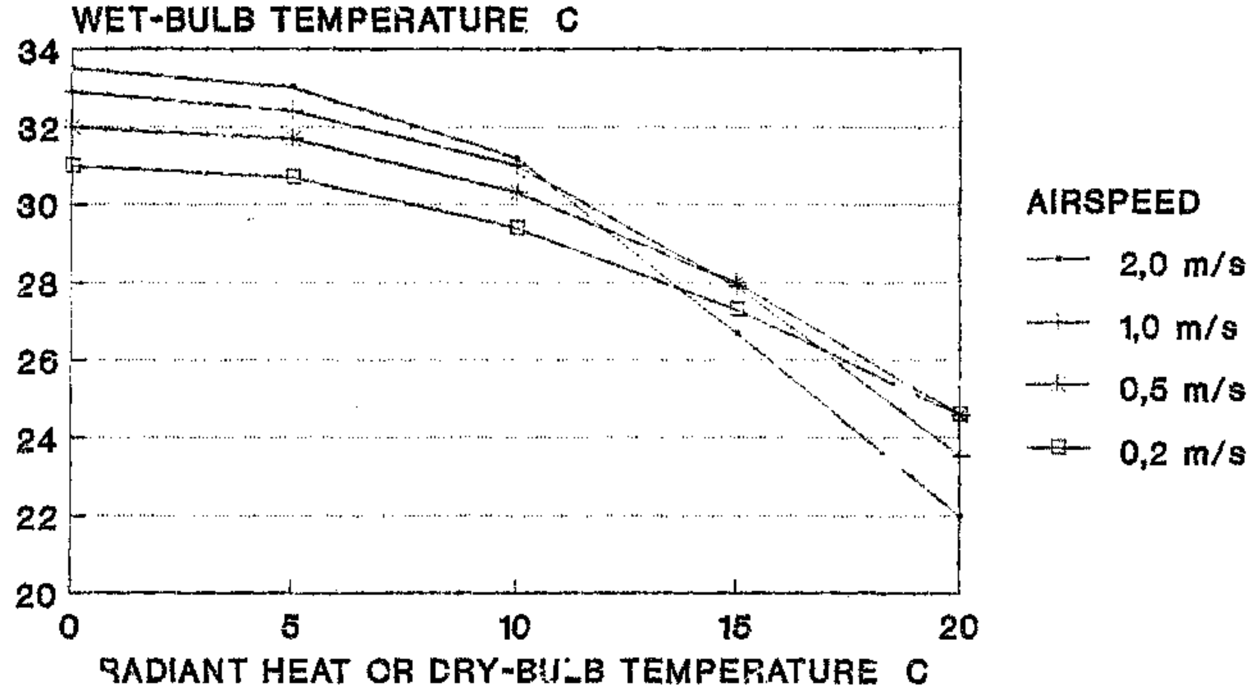
2.2 LITERATURE SURVEY

The variance between the psychrometric wetbulb temperature (tpwb) and windspeed is shown in figure .

This is true if the gap between the tpwb and radiant and/or drybulb temperatures do not exceed 2°C. The entire picture changes if the radiant temperature is increased.

Figure 2.3 - Cooling power from wetbulb temperature and windspeed

WETBULB TEMP. AND WIND SPEED REQUIRED TO COMPENSATE FOR AN ELEVATION IN RADIANT AND DRYBULB TEMPERATURE

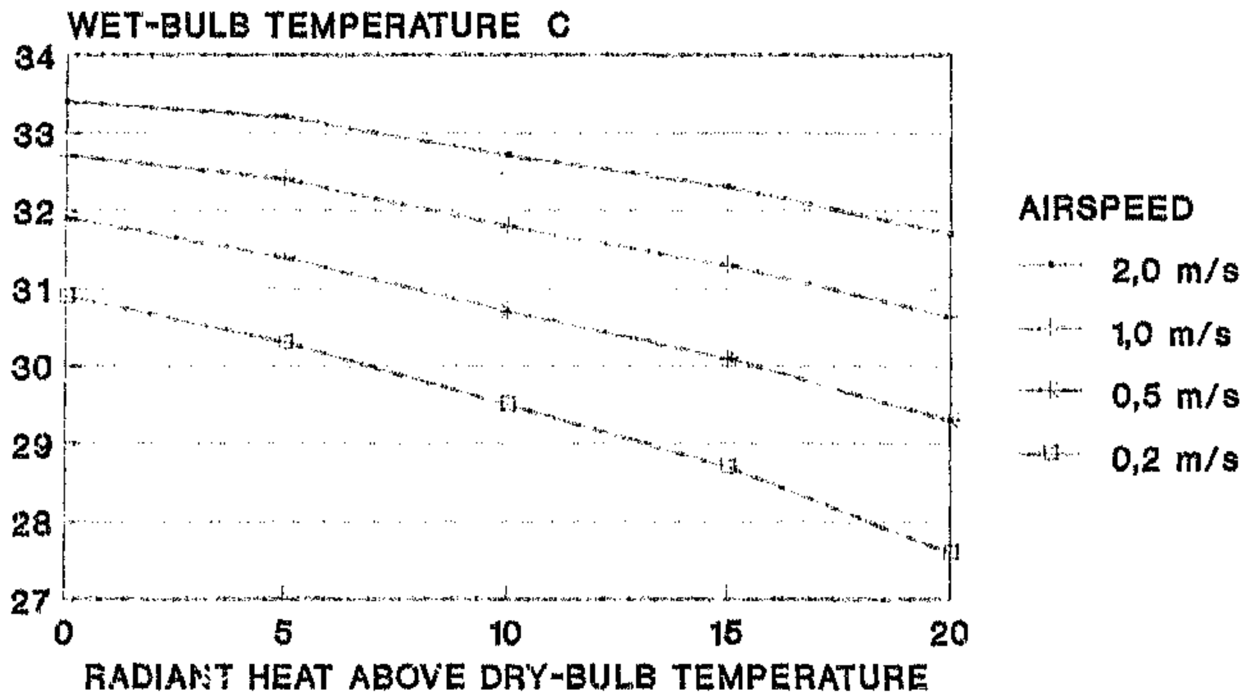


moderate work(180 W/m^2),ta=tr,t=100KPa
sweat rate= 0,45kg/m^2h
mean skin temperature=35.1 C fig 2.3

Little information exists when this gap increases. Stewart (1984:548) shows (figure 2.4) the required wetbulb temperature with an increase in the said gap. Basically this work needs to be duplicated for diesel vehicle operators.

Figure 2.4 - Wetbulb temperature and windspeed required to compensate for an elevation in radiant heat

WETBULB TEMP. AND WIND SPEED REQUIRED TO COMPENSATE FOR AN ELEVATION IN RADIANT ABOVE DRYBULB TEMPERATURE



moderate work(180 W/m^2),ta=tr,t=100KPa
sweat rate= 0,45kg/m^2h
mean skin temperature=35,1 C Fig 2.4

The research can be divided into three distinct sections namely:-

- Specific cooling power of air due to external environmental factors
- Heat stress analysis on factors in drivers cabin
- Stress due to noise exposure

Kielblock, J. (1988:01) states that no scientific work has been done on the evaluation of heat stress of diesel powered vehicle operators. The impact of external ambient conditions needs to be evaluated. The effect of clothing has not been taken into account in any of the COMRO's studies concerning operators.

Heat stress due to external environmental factors can be evaluated in several ways. Chompusakdi (1980:41), Stewart and ASHOSH (1974) have been consulted and the following combination indicate the heat stress and strain methods available:-

1. Wet-bulb globe temperature (WBGT) Index. This index number consists of a simple weighting of the globe temperature (tg), natural wetbulb temperature (tnwb) and natural drybulb temperature.

2. Predicted Four Hour Sweat Rate (P4SR) Index developed by McArdle Chompusakdi (1980). P4SR predicts total sweat loss (litres) during a four hour exposure.

3. Heat Stress Index by Belding and Hatch (1955) is based on the physical analysis of heat exchange between a hot body and the ambient air. The index number describing the heat stress between a hot body and the ambient air is expressed as a percentage of evaporative heat loss required for heat balance (Ereq) and the maximum evaporative capacity (Emax).

4. Effective Temperature (ET) was devised originally by Houghton and Yaglou Chompusakdi (1980) as a comfort Scale. This scale is an empirical sensory index which combines into a single value (ET) the effects of temperature, humidity, and air movement on the human body. A derivitive is the corrected effective temperature incorporating globe temperature.

Other heat stress indices include:

- Relative strain (RS) index
- Reference index (RI)
- Wet globe temperature index (WGT)
- Corrected effective temperature (CET)
- Operative temperature (OT)
- Combined heat stress index (HSICP)
- Belding-Hatch heat stress index (HSIBH & BC)

Literature on these indices have been consulted, with specific reference to Kamon (1981:611) using effective heat strain index (EHSI) and the wetbulb globe temperature (WBGT) index as described by ISO No. 7243 (1982).

It is therefore necessary to calculate effective temperature, wetbulb globe temperature, specific cooling power of the air, metabolic work rate and the resultant heat stress of the drivers.

Finally the radiant heat will also be indicated.

Heat stress analysis on factors in the drivers cabin will be added to the evaluation of ..rnal factors as above using data from the specific research and directives from OSHASH (1974).

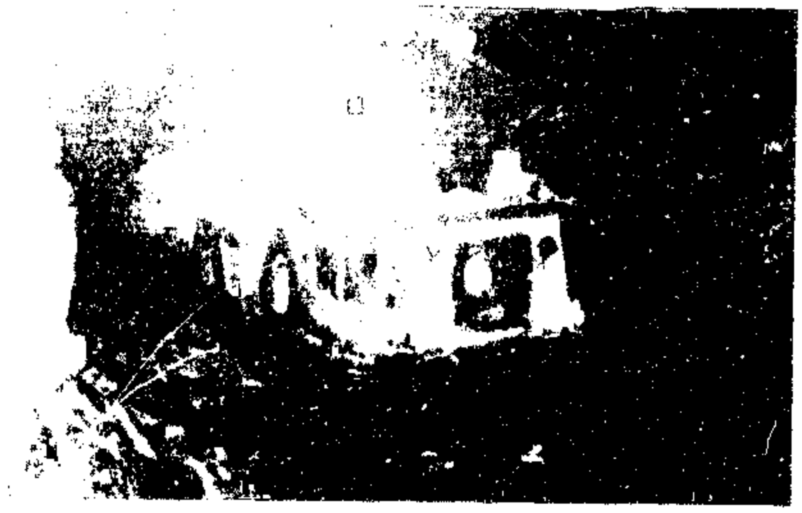
The necessary work and research was done at Western Areas Gold Mining Company's 83 TMMM project.

Seven vehicles and operators where tested in four different categories. A list of these is shown in the table below and illustrated as figure 2.5.

Vehicle type	Power Rating	Supplier
Load-haul dumper Type 1	2 X 144 kW	Wagner
Load-haul dumper Type 2	1 X 216 kW	GHH
Dumptruck 18 ton (DT)	3 X 180 kW	Wagner
Utility Vehicle (UV)	1 X 63 kW	Wagner

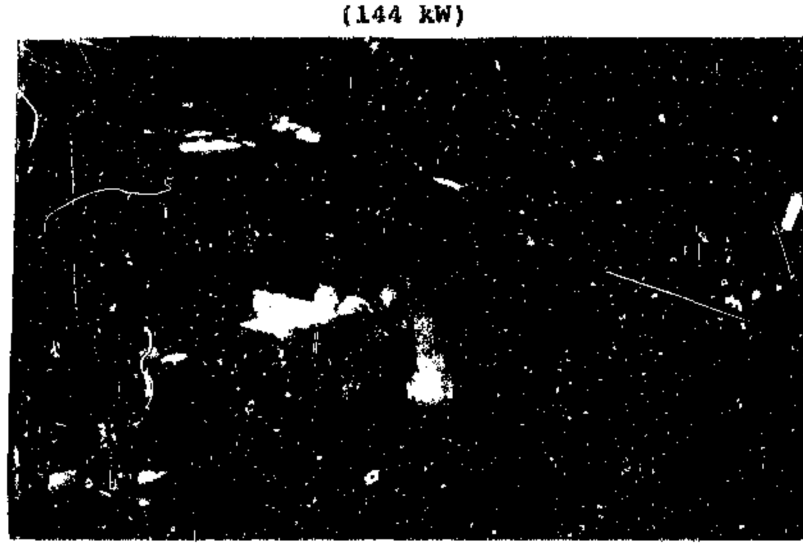
Vehicles used during the evaluation.

The monitoring period consisted of two (2) days per operator at average 7½ hours per day continuous driving.



LOAD HAUL DUMPER (SCOOP)

(144 kW)

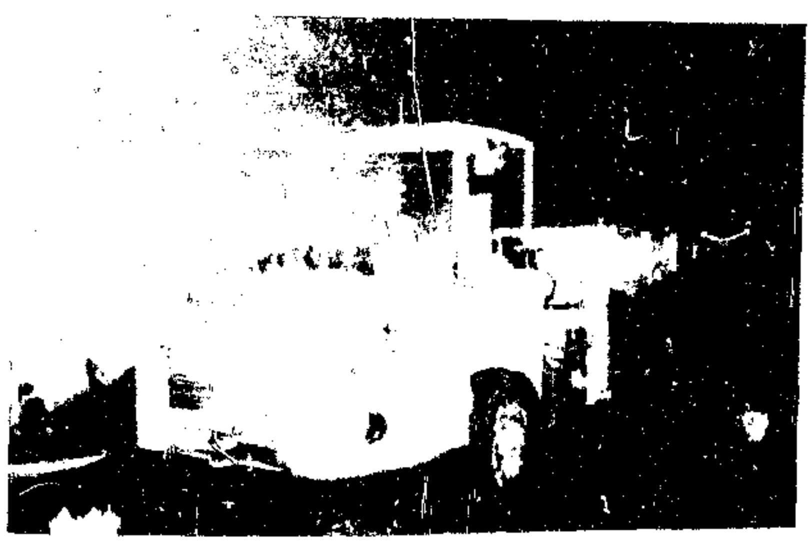


LOAD HAUL DUMPER

(216 kW)

Figure 2.5 - Vehicles used during the Evaluation

DUMPTRUCK
(18 Ton)



UTILITY VEHICLE

Figure 2.5 - Vehicles used during evaluation

2.3. OVERVIEW OF THEORETICAL SOLUTION

The cost of the trackless mechanized mining vehicles is high. The rapid and efficient use of these vehicles plays an important, if not the most important part in the economics of trackless mining.

Operators of these units must therefore be of the best from a psychological and physiological point of view. External factors must be able to enhance these capabilities - if possible. If not, detremental external influences must be eliminated or limited to minimize the deficiencies of the operators.

To achieve this, the entire spectrum of external influences needs to be evaluated. It is necessary to evaluated most of, if not all, the heat stress indices available. Comparison of these indices must be done to determine the most efficient method of controlling this unique and harsh environment.

A redesign of the operators cabin is necessary so as to make it more acceptable and reduce the aggravating influence of radiant heat in this area.

Listed in appendix 4 (page 94), are the formulae used to calculate the metabolic work rate, effect of clothing to evaporative heat transfer, effective and wetbulb globe temperature. The specific cooling power of the air and heat stress figures are also shown.

It is necessary to generate a computer program to evaluate the heat stress indices as an ongoing project. This will allow the rapid determination of corrective action required.

Determining the noise exposure of the operator and deciding on the necessary controls required to reduce noise is required. Tarter (1990:685) established that high noise levels increases hypertension. Mean hearing loss was 28,3 dBA amongst the black men and 45,3 dBA amongst the white workers at the 4000 Hz frequency band. Also 31,9% of the black men and 22,0% of the white men had hypertension, defined as diastolic blood pressure higher than 90mm HG and/or currently taking hypertensive medication. These tests were conducted in an automotive assembly plant. Short term noise exposure in the 90 to 100 dBA range in normotensive and hypertensive patients has been to raise diastolic blood pressure 7 to 12 %. This in turn influences the metabolic work rate and stress index. As part of the proposed solution to make the machine more ergonomically acceptable to man - silencing of the exhaust system is recommended.

Hearing loss can therefore be theoretically determined, using the noise levels over the total exposure period. A maximum of 85 dBA is allowed during an 8 hour period of continuous exposure.

It is important to note that operators spend more than seven to eight hours on these vehicles.

In order for operators to work efficiently at the highest productive rate, two types of controls are necessary :

Administrative controls such as:

(a) Training and education to recognise the first signs of heat exhaustion.

(b) Proper and regular medical surveillance.

(c) Self pacing during the 7½ hour shift. More frequent resting periods may result in a more alert and productive operator.

(d) Acclimatization of operators at temperatures simulating real conditions.

(e) Encouragement of operators to drink water more frequently and to avoid food with a high fat content.

Physical or engineering controls may include:

(a) A cool room for occupation during rest periods.

(b) Shielding operator from radiant heat.

(c) Evaporative cooling in the cabin.

(d) Micro climate cooling in the form of an airconditioned vest.

(e) Silencing of exhaust parts.

(f) Deflection of engine heat from cabin.

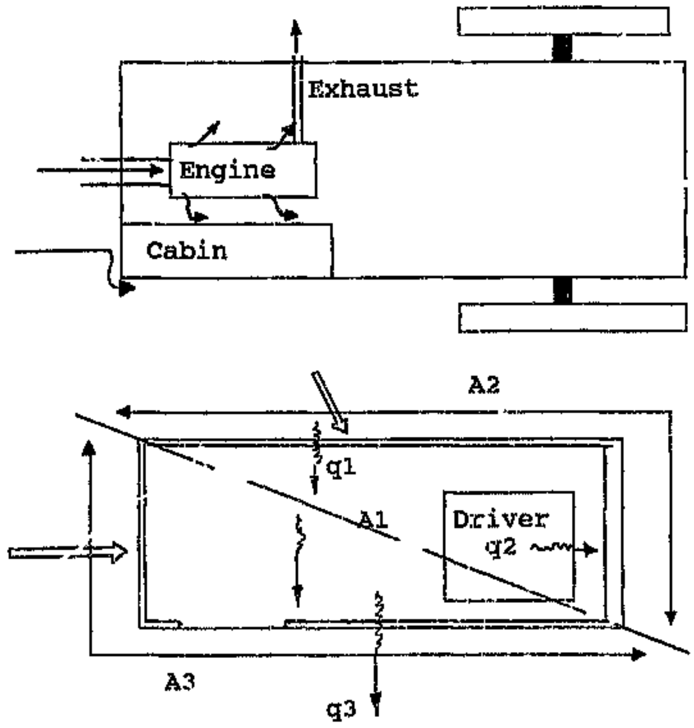
(g) Heat stress analysis as a matter of routine and the reduction of external environment conditions making an impact on the operator.

NOTE : that an explanation of the heat generated in the drivers cabin is necessary at this point .

Heat content of the drivers cabin can be devided into :

$$q\ cabin = q1 + q2 - q3$$

Where : q1 is heat from engine impinging on conditions in the cabin, W/m^2.
q2 is heat generated by the driver, W/m^2
q3 is heat loss due to ambient air cooling effect, W/m^2.



Heat transfer is the combination of the radiant and conductive heat transfer mechanisms as major driving forces, with convective and evaporative heat transfers as minor sources or sinks

These heat sources and heat sinks are explained in appendix K (page 109).

2.4 PRACTICAL EVALUATION AND RESULTS

The Tests

Base Case

In order to conduct a comparative study, the incumbents' METABOLIC WORK RATE were tested in ambient conditions not conducive to heat stress.

The test was carried out above ground in a closed room with temperatures of 24,0/26,5/26,5 °C for temperature wet bulb, temperature dry bulb and temperature radiant respectively.

The operators were tested for heart rate and oral temperature before being exposed to a work rate of 54, 70 and 100 watt. This was achieved by allowing the subjects to do stepping exercises at a specific rate simulating the above work rates.

The height of the steps corresponded to the persons weight and relative fat derived from skinfold measurements and subsequent calculations of relative fat.

The ratio of height to body mass was taken to calculate the total body area in m^2.

Heart rates were taken to determine VO_2 max which is the maximum oxygen uptake and the metabolic work rate.

<u>On site Testing</u>

Two specific sets of measurements were taken to determine the heat stress Index:

- <u>Physiological parameters</u>

  Portable heart rate monitors (Type Oxford Medilog MR15) were used to monitor the operators over the full shift. Also taken was the skin temperature using a thermistor and logging the data on a <u>GRANT</u> data logger (Type Squirrel : No 8216). These instruments are shown in figure 2.6 .

- <u>Environmental parameters</u>

  The parameters necessary to determine the various heat stress indices were taken over the same period. The instruments used conformed to ISO 7243 (1982). Grant data loggers (Type Squirrel Ser No. 8217 and 8219) were used to collate the necessary information. These instruments are also shown in figure 2.6.

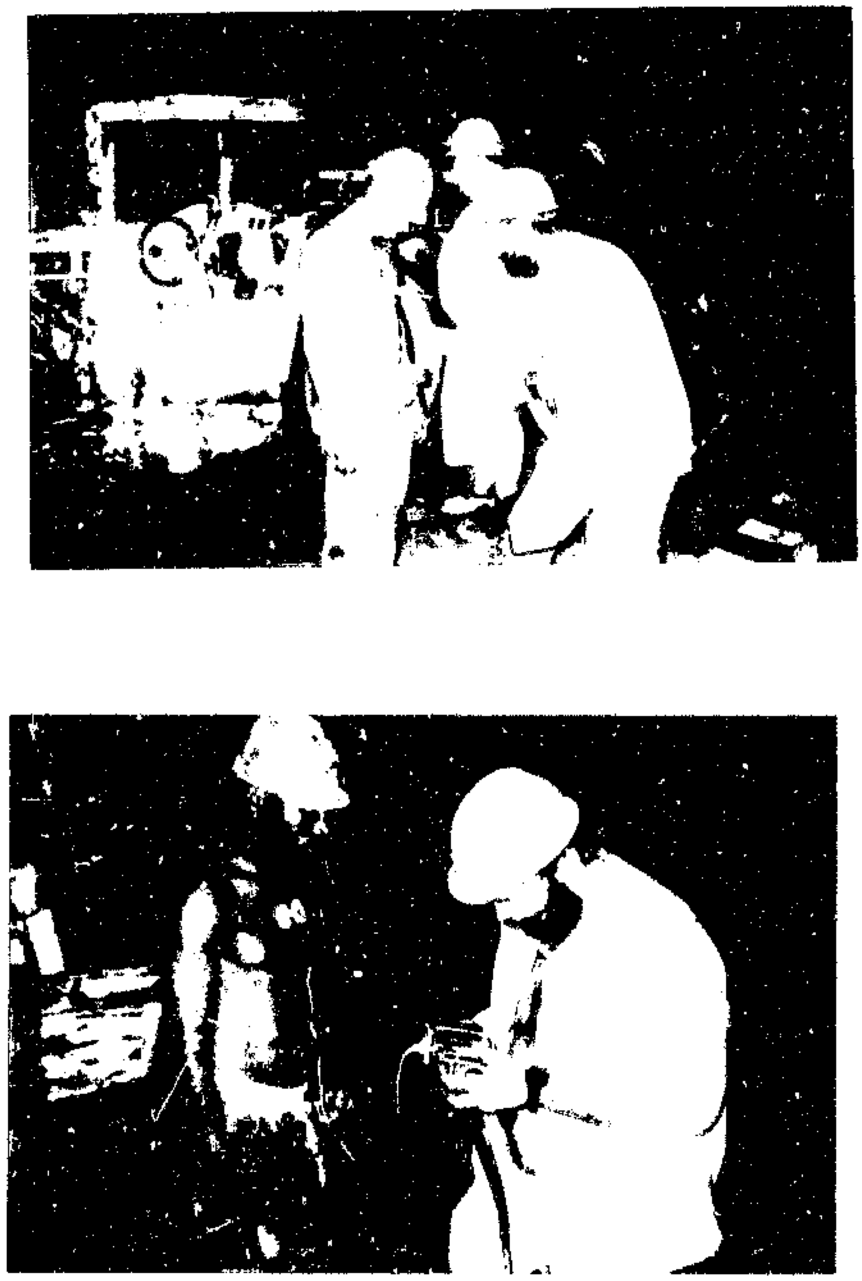


Figure 2.6 - MEDILOG for heart rate recording

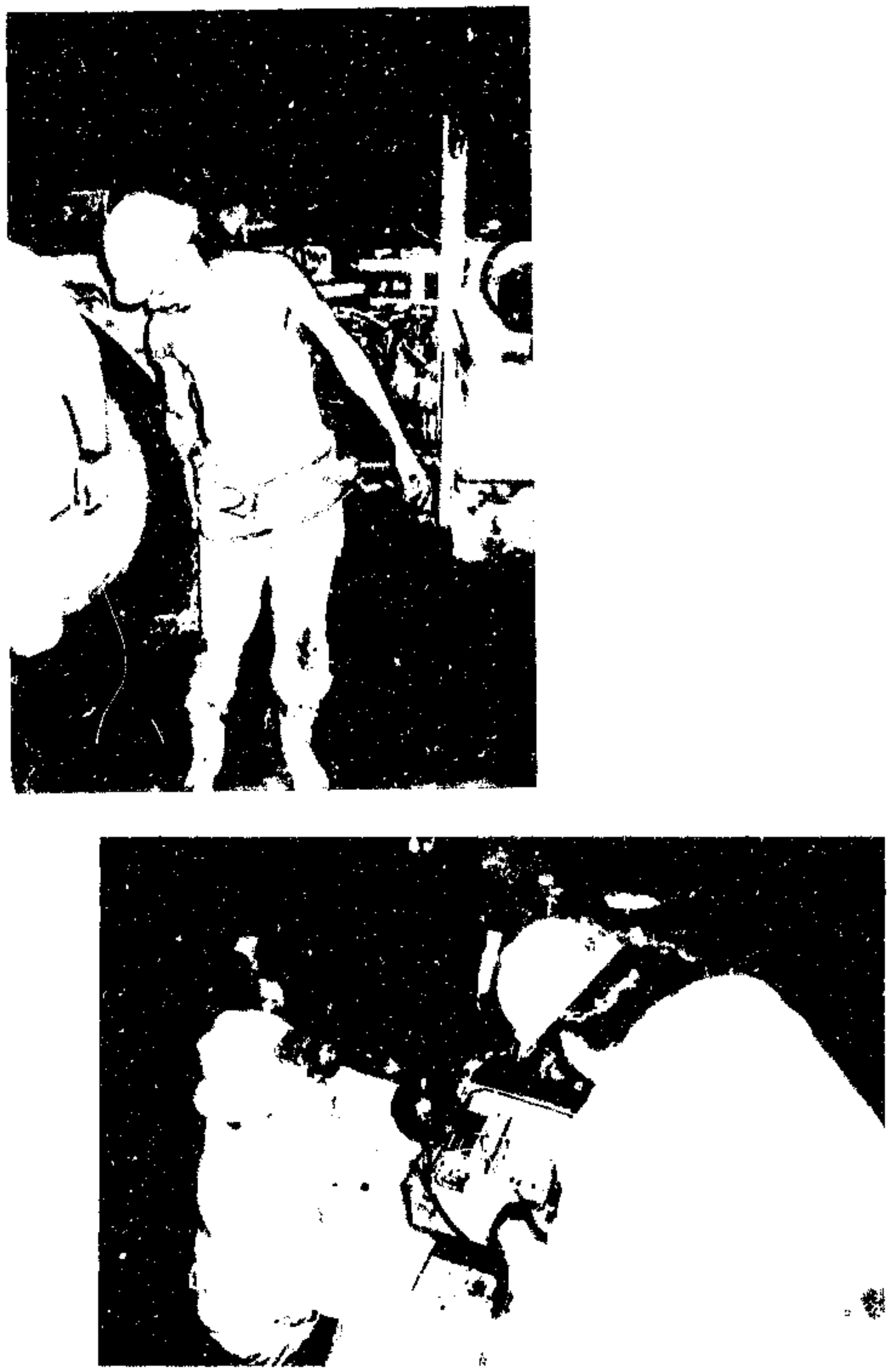


Figure 2.6 - Preparing for tests

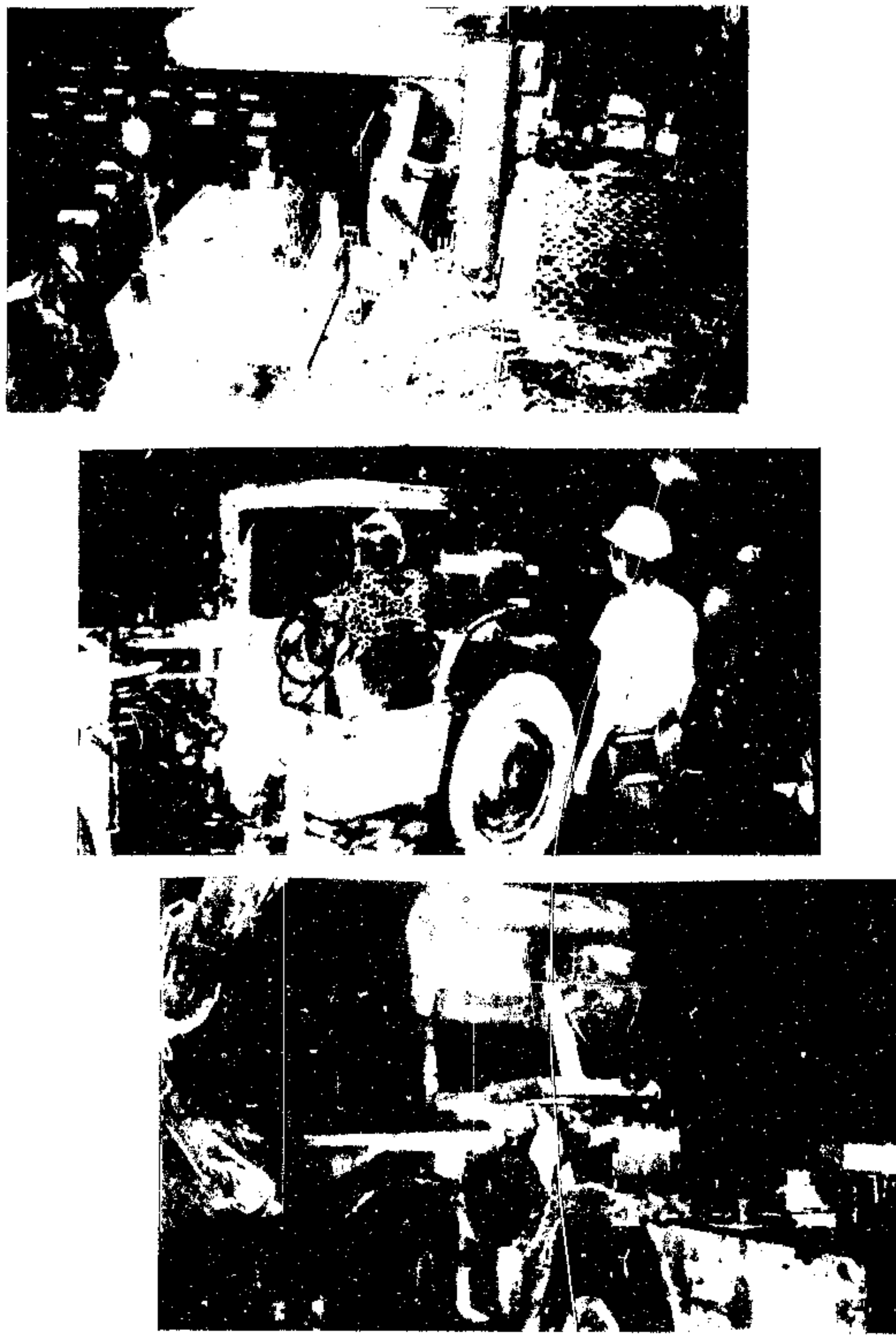


Figure 2.6 - Trails taking place

The Results

Heat :

An example of the results is attached as per Appendix I (page 108). The same format was used to evaluate all the drivers. The operators are exposed to heat as per table 2.2. - These are average figures. However, during certain periods as seen in the figure 2.7 series - conditions change and the SCPA drops to figures below 180 W/m^2. Again SCPA being the specific cooling power of the air required for cooling the metabolic heat generated.

Vehicle Type	Stress	WBGT	SCPA	Metab work rate	Eff Temp
	(Yes/No)	(°C)	(W/m2)	(W/m2)	(°C)
LHD Type 1	Y	32,5	240	180	38,1
LHD Type 2	Y	38,9	180	195	36,0
DT	N	35,1	200	175	41,7
UV	N	34,0	250	180	31,5

Table 2.2 - Average exposure of drivers to the environment

The above results were obtained using the formulae in Appendix H (page 94) - after Kamon and summarised in Appendix J (page 114).

The work was checked using the ISO 7243 and formulae by Stewart (Appendix H). NIOSH recommendation and formulae forms part of this appendix.

- Heat rejection by the vehicle engine influencing the wetbulb globe temperature (WBGT) in the drivers cabin is reflected in the table 2.3 .

Operator Vehicle type		WBGT - °C
LHD	Type 1	32,5
LHD	Type 2	38,9
DT		35,1
UV		34,0

Table 2.3 - WBGT Drivers cabin

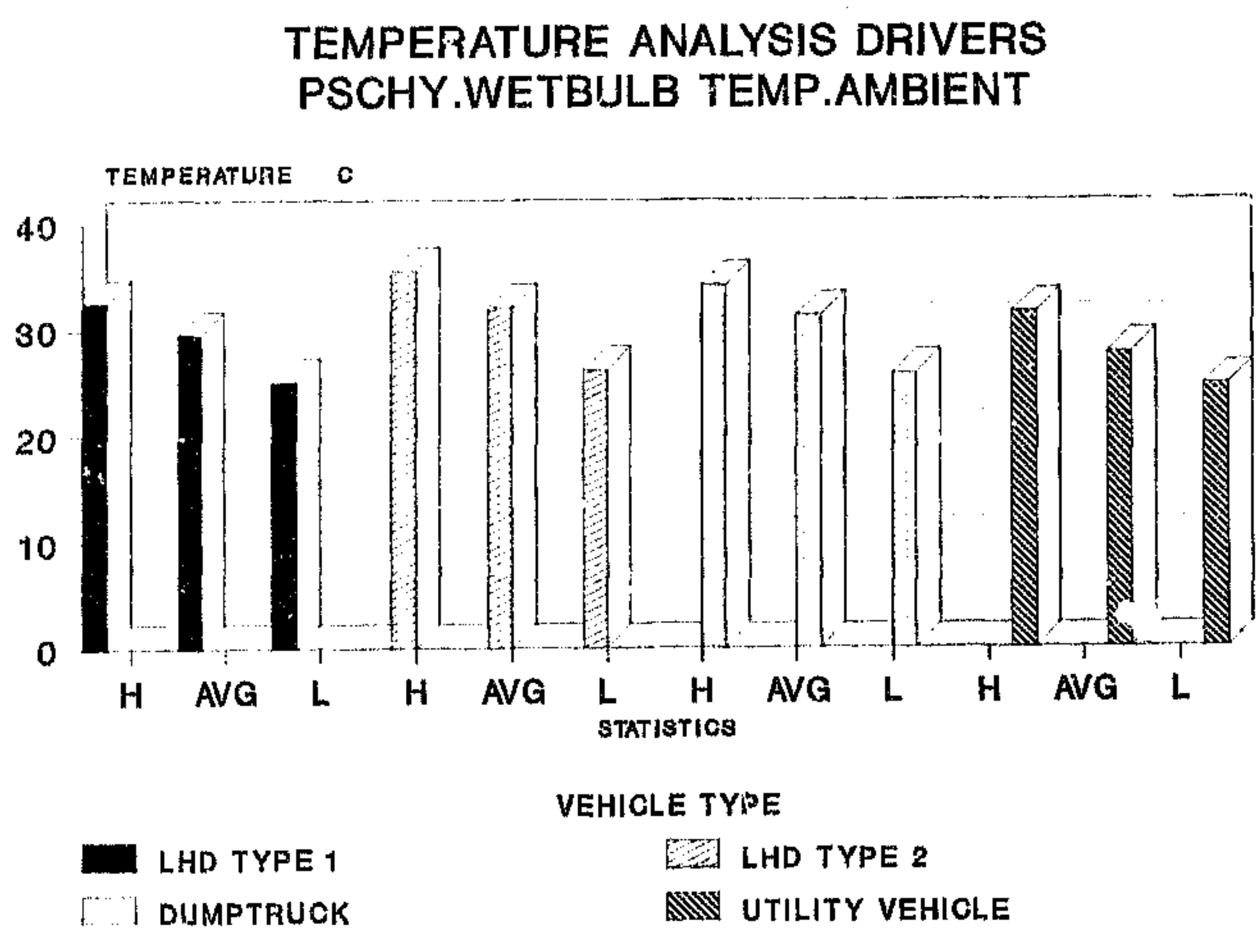
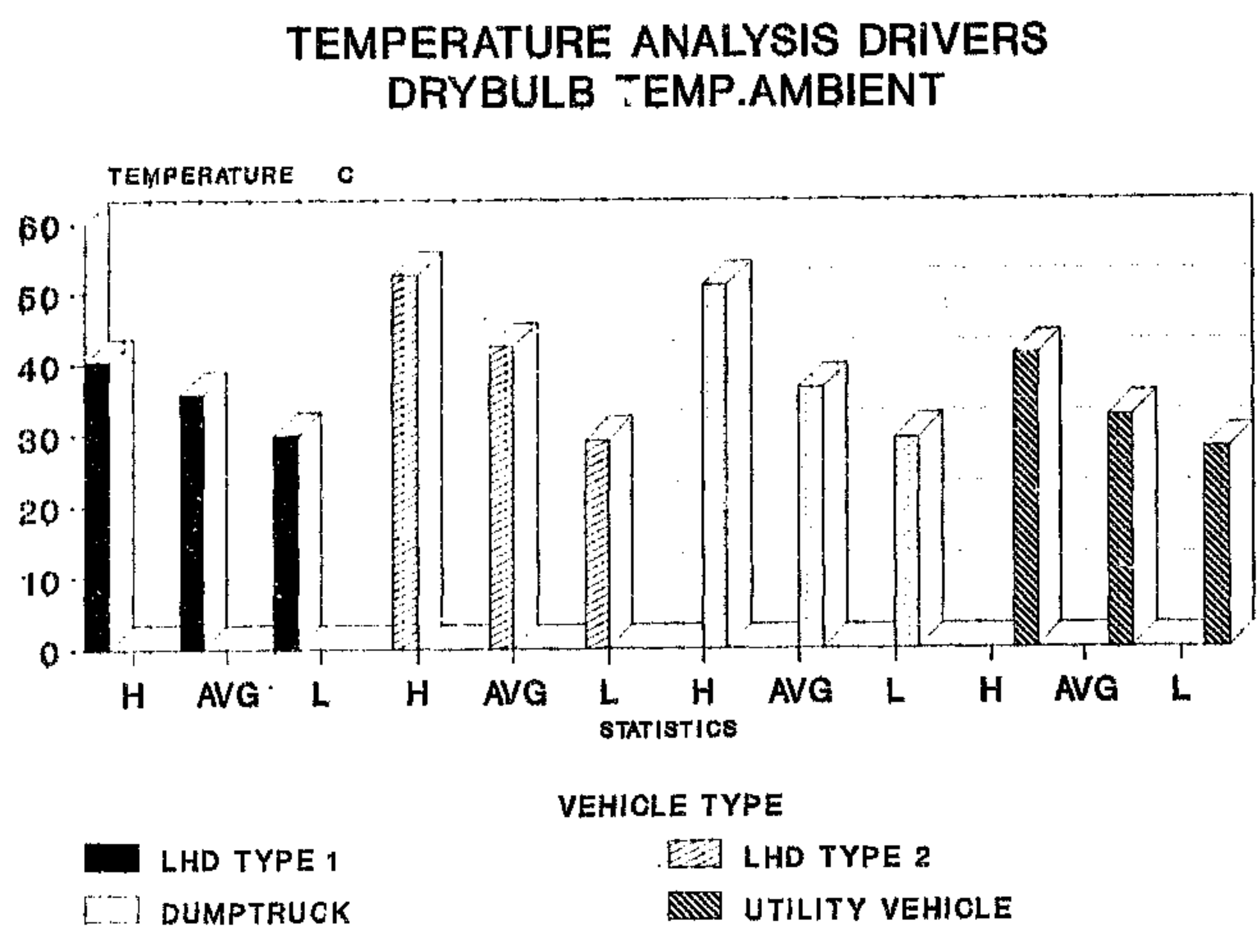
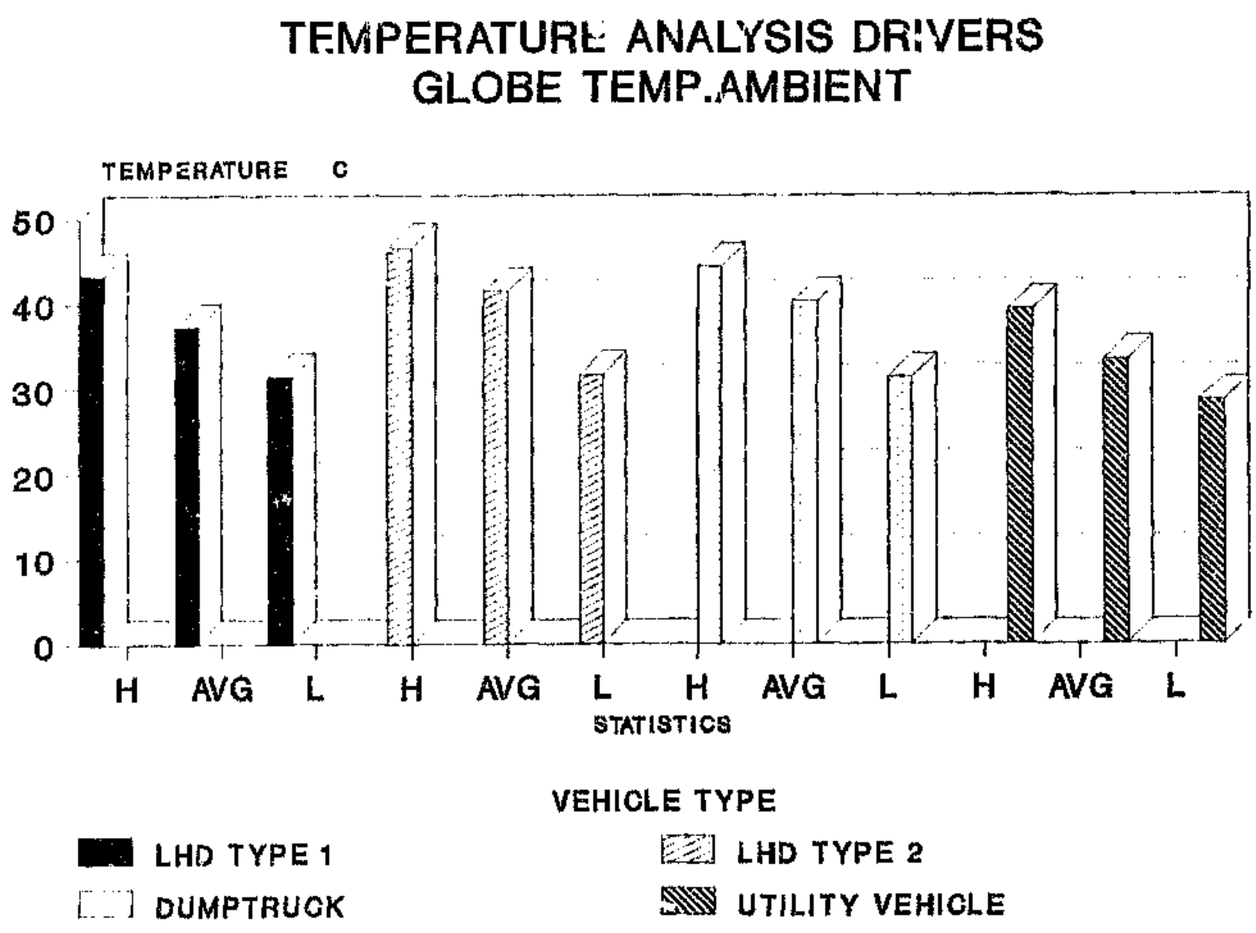

TEMPERATURE ANALYSIS DRIVERS
PSCHY.WETBULB TEMP.AMBIENT
TEMPERATURE C
40
30
20
10
0
H
AVG
L
H
AVG
L
H
AVG
L
H
AVG
L
STATISTICS
VEHICLE TYPE
LHD TYPE 1
DUMPTRUCK
LHD TYPE 2
UTILITY VEHICLE

FIG 2.7 a



TEMPERATURE ANALYSIS DRIVERS
DRYBULB TEMP.AMBIENT
TEMPERATURE C
60
50
40
30
20
10
0
H
AVG
L
H
AVG
L
H
AVG
L
H
AVG
L
STATISTICS
VEHICLE TYPE
LHD TYPE 1
LHD TYPE 2
DUMPTRUCK
UTILITY VEHICLE

FIG 2.7 B


TEMPERATURE ANALYSIS DRIVERS
GLOBE TEMP.AMBIENT
TEMPERATURE C
50
40
30
20
10
0
H
AVG
L
H
AVG
L
H
AVG
L
H
AVG
L
STATISTICS
VEHICLE TYPE
LHD TYPE 1
LHD TYPE 2
DUMPTRUCK
UTILITY VEHICLE

56 FIG 2.7 C

TEMPERATURE ANALYSIS DRIVERS
RADIANT TEMP.AMBIENT

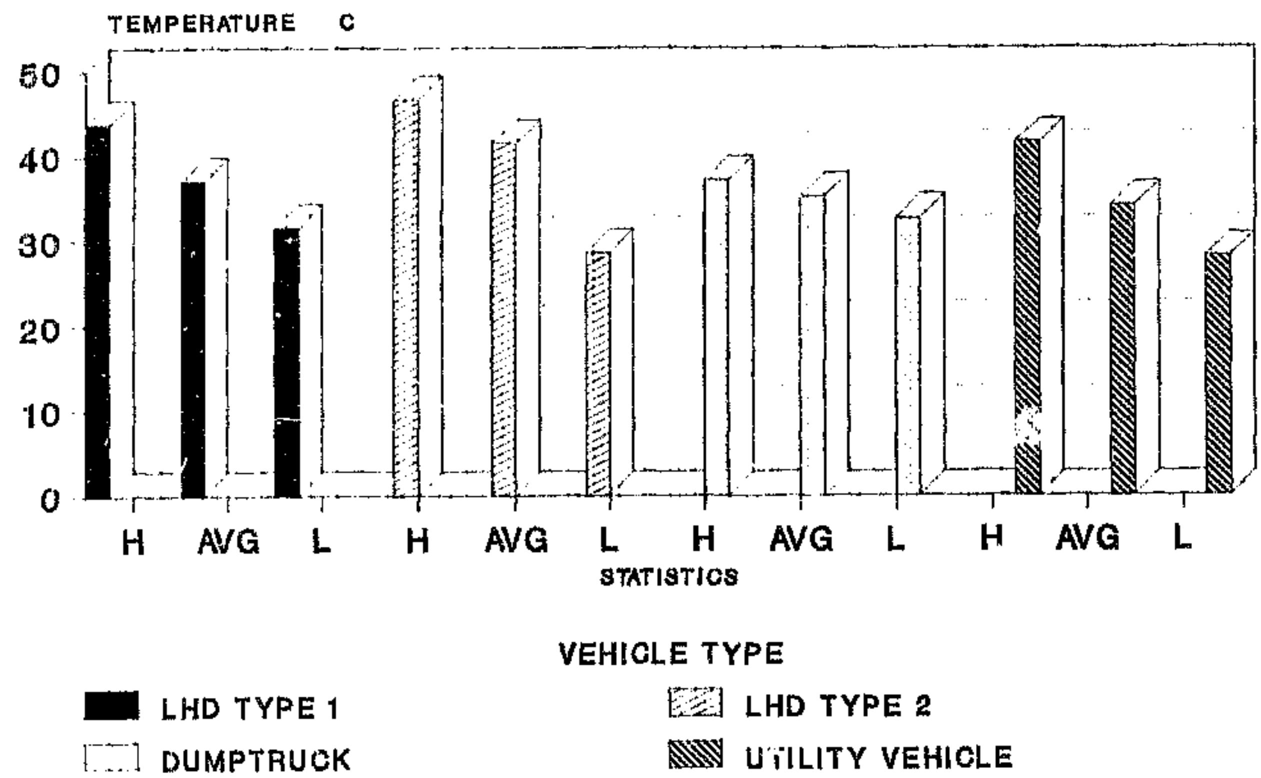


FIG 2.7 D

TEMPERATURE ANALYSIS DRIVERS
EFFECTIVE TEMP.AMBIENT

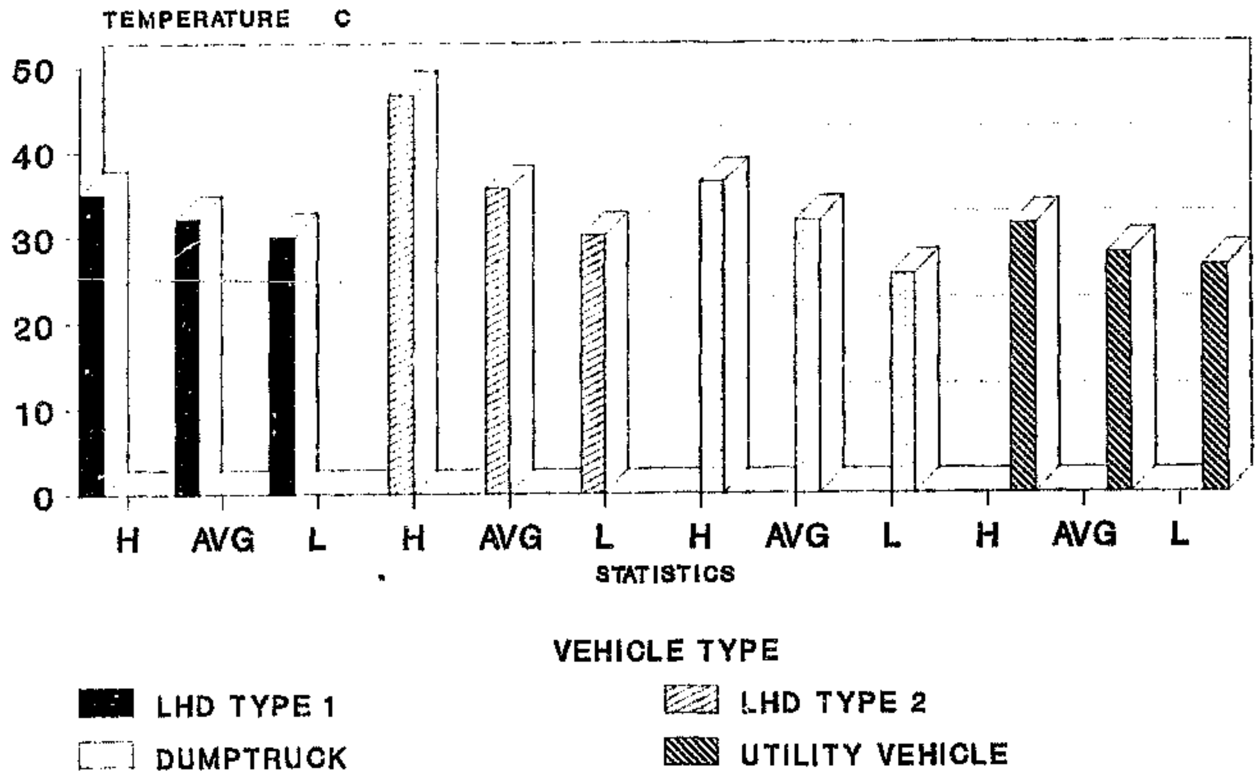


FIG 2.7 E

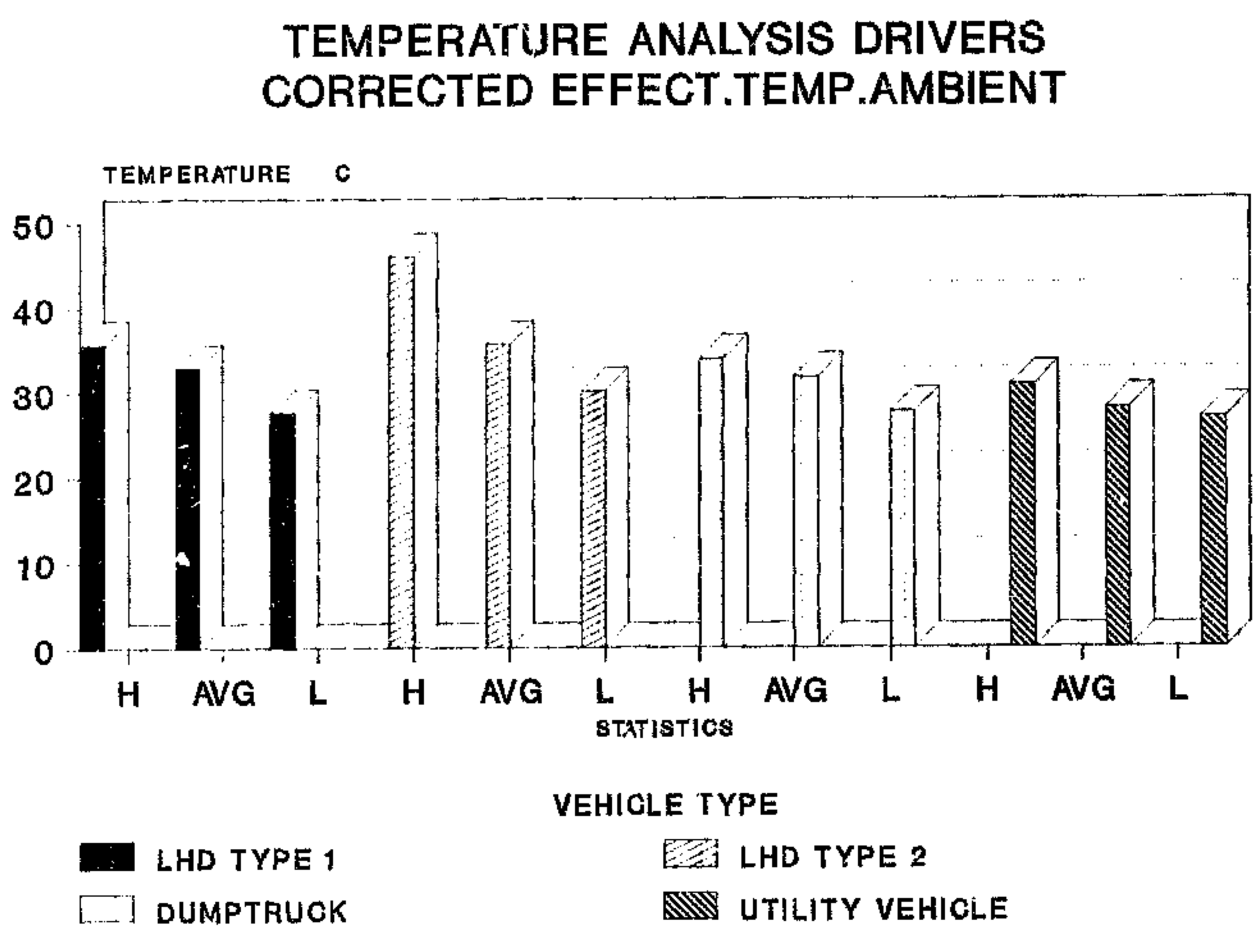

TEMPERATURE ANALYSIS DRIVERS
CORRECTED EFFECT.TEMP.AMBIENT
TEMPERATURE C
50
40
30
20
10
0
H
AVG
L
H
AVG
L
H
AVG
L
H
AVG
L
STATISTICS
VEHICLE TYPE
LHD TYPE 1
LHD TYPE 2
DUMPTRUCK
UTILITY VEHICLE

FIG 2.7 F

TEMPERATURE ANALYSIS DRIVERS
WET KATA READING AMBIENT

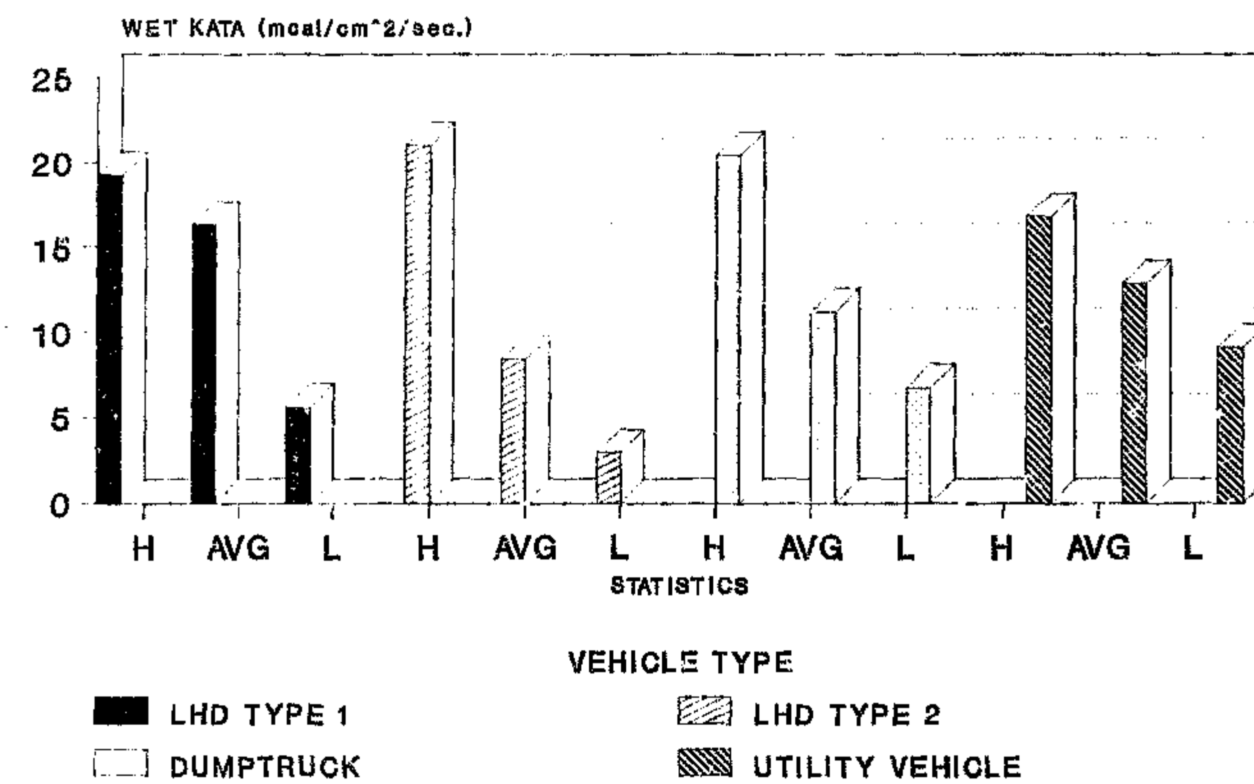


FIG 2.7 G

TEMPERATURE ANALYSIS DRIVERS
METABOLIC WORK RATE DRIVERS

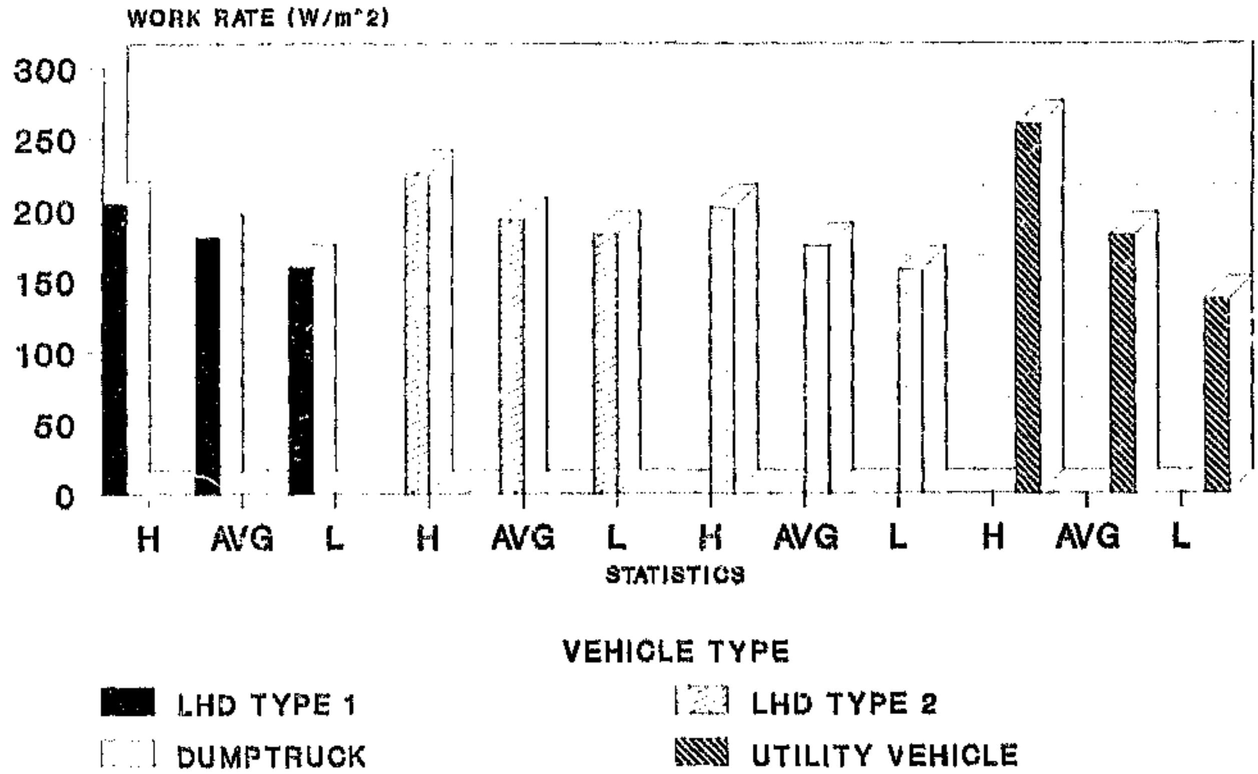


FIG 2.7 H

TEMPERATURE ANALYSIS DRIVERS
HEART RATE DRIVERS

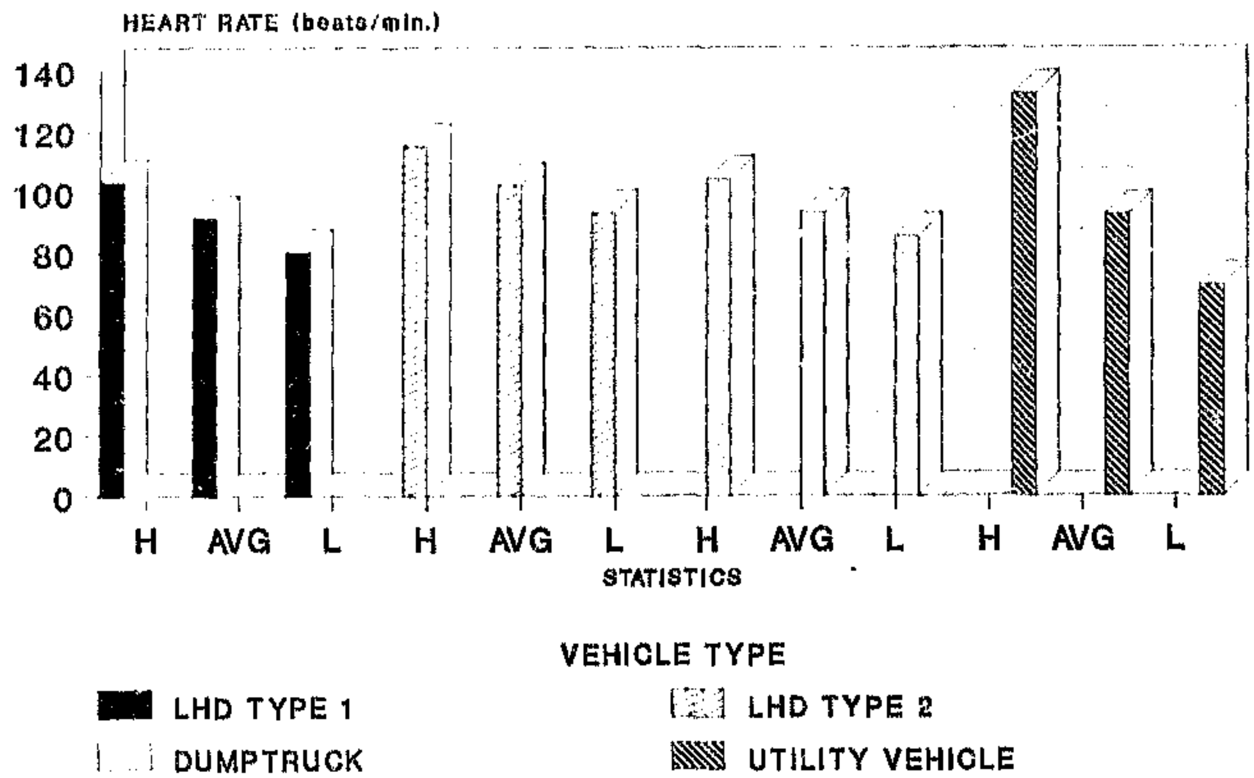


FIG 2.7

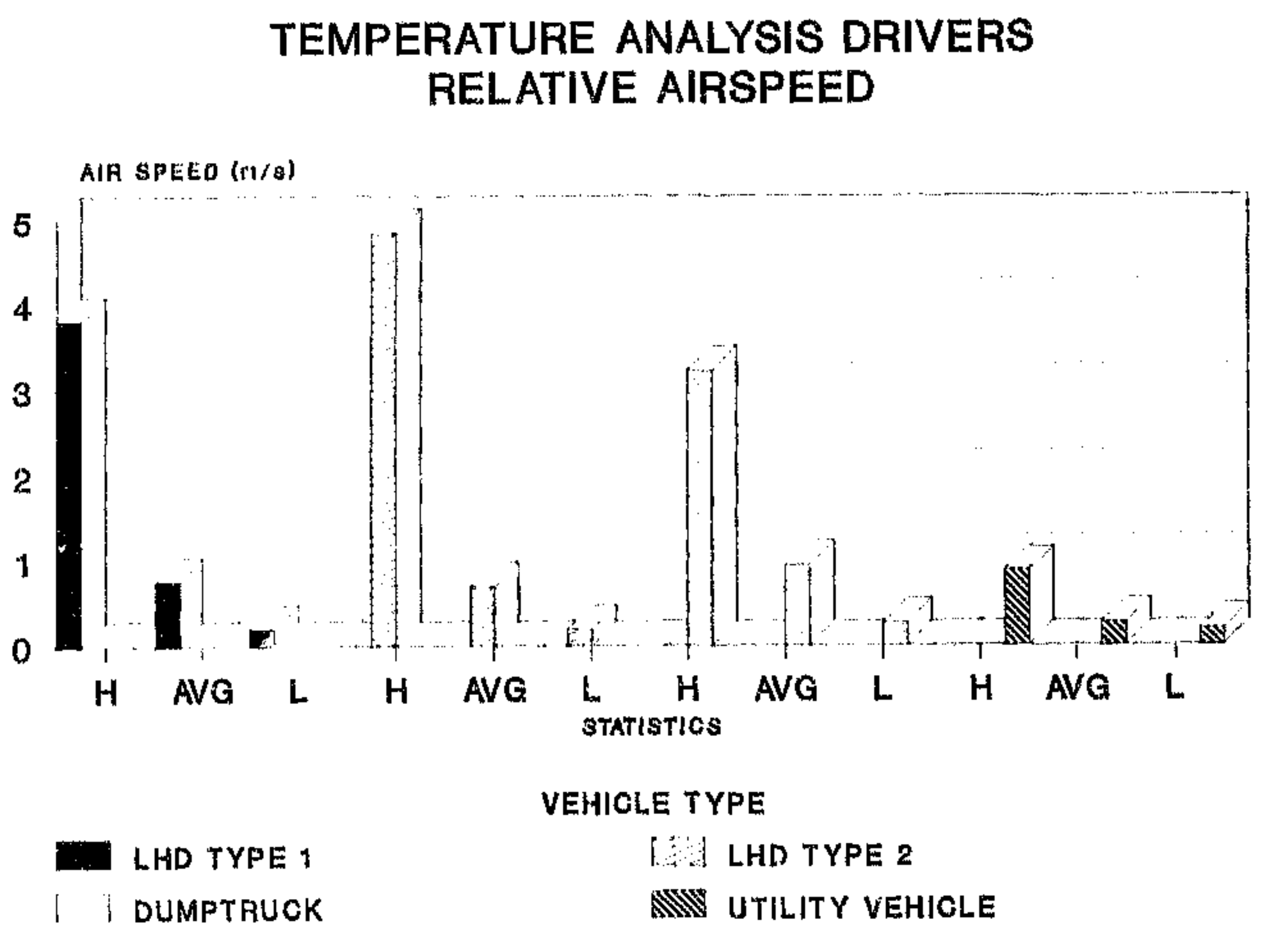
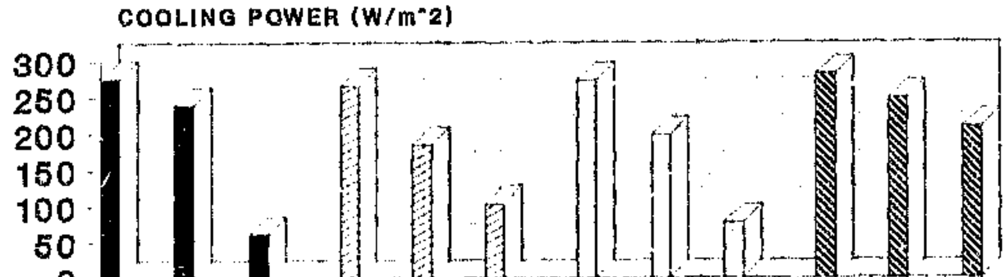

TEMPERATURE ANALYSIS DRIVERS
RELATIVE AIRSPEED
AIR SPEED (m/s)
5
4
3
2
1
0
H
AVG
L
H
AVG
L
H
AVG
L
H
AVG
L
STATISTICS
VEHICLE TYPE
LHD TYPE 1
LHD TYPE 2
DUMPTRUCK
UTILITY VEHICLE

 FIG 2.7 J

TEMPERATURE ANALYSIS DRIVERS
SPECIFIC COOLING POWER OF THE AIR



	H	AVG	L	H	AVG	L	H	AVG	L	H	AVG	L
LHD TYPE 1	274	238	60									
LHD TYPE 2				264	183	102						
DUMPTRUCK							272	197	76			
UTILITY VEHICLE										281	247	207

STATISTICS

VEHICLE TYPE

LHD TYPE 1 — LHD TYPE 2 — DUMPTRUCK — UTILITY VEHICLE

FIG 2.7 K

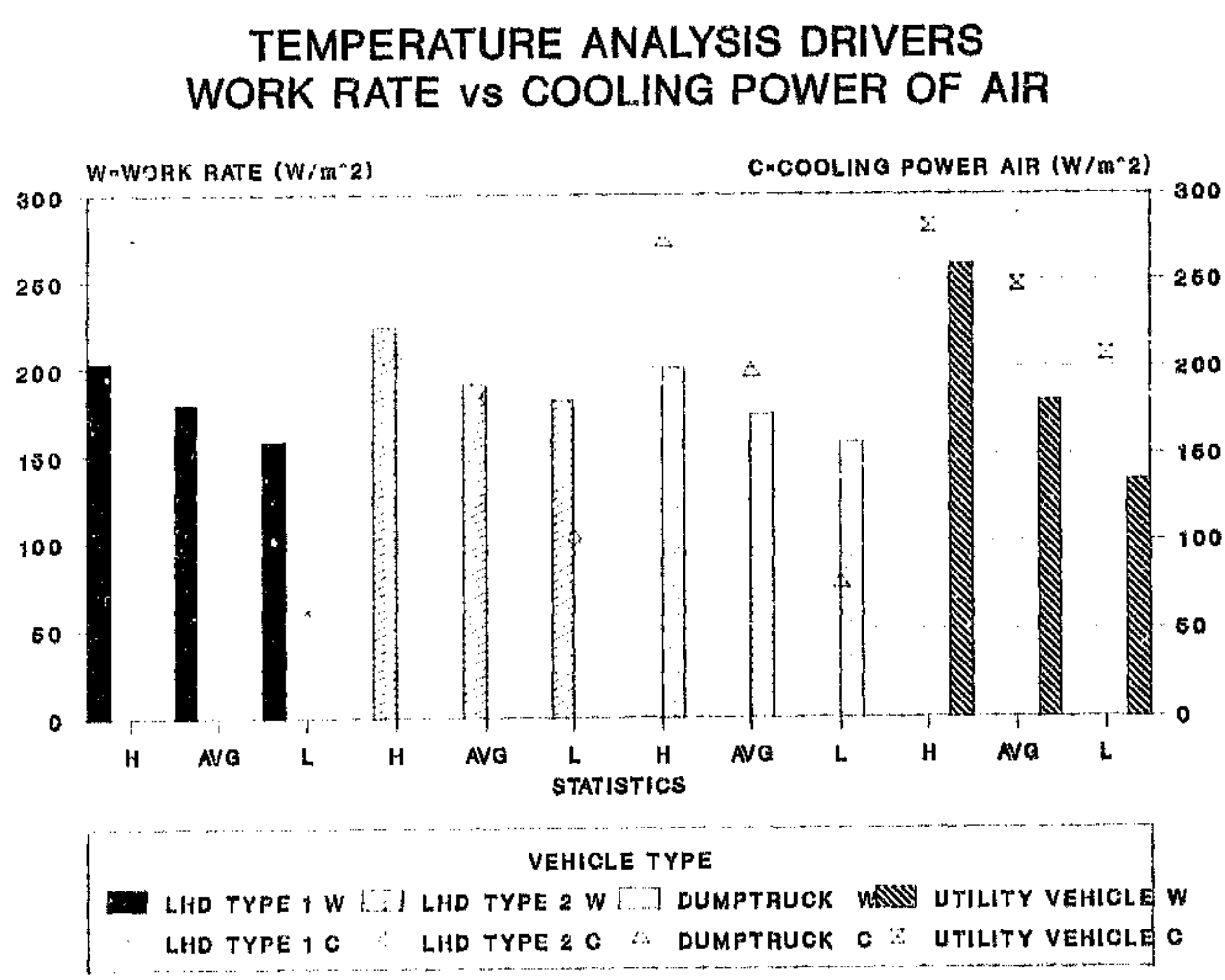
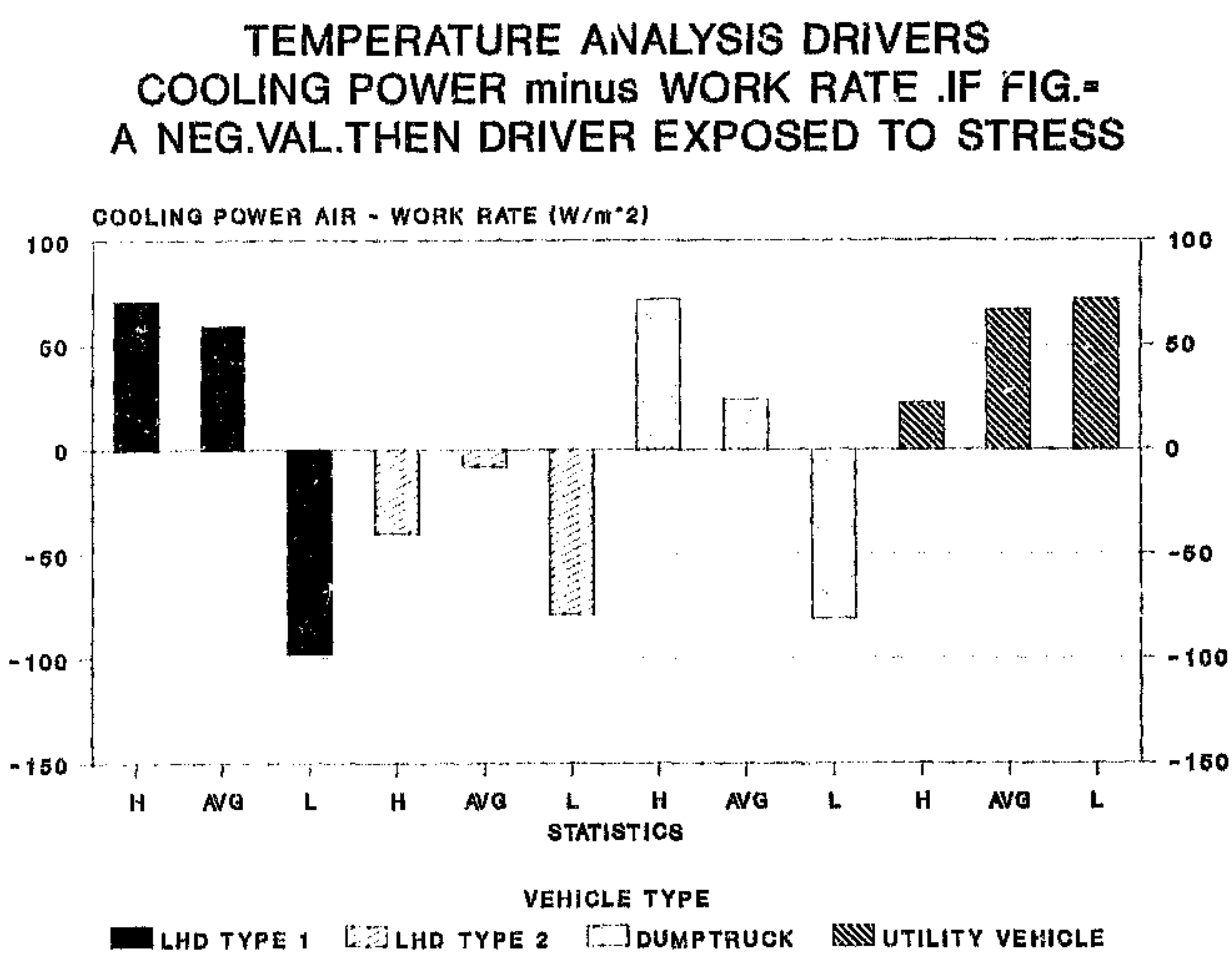

TEMPERATURE ANALYSIS DRIVERS
WORK RATE vs COOLING POWER OF AIR
W=WORK RATE (W/m^2)
C=COOLING POWER AIR (W/m^2)
300
250
200
150
100
50
0
H
AVG
L
STATISTICS
VEHICLE TYPE
LHD TYPE 1 W
LHD TYPE 2 W
DUMPTRUCK W
UTILITY VEHICLE W
LHD TYPE 1 C
LHD TYPE 2 C
DUMPTRUCK C
UTILITY VEHICLE C

FIG 2.7 L



TEMPERATURE ANALYSIS DRIVERS
COOLING POWER minus WORK RATE .IF FIG.=
A NEG.VAL.THEN DRIVER EXPOSED TO STRESS
COOLING POWER AIR - WORK RATE (W/m^2)
100
50
0
-50
-100
-150
H
AVG
L
STATISTICS
VEHICLE TYPE
LHD TYPE 1
LHD TYPE 2
DUMPTRUCK
UTILITY VEHICLE

66

FIG 2.7 M

HEAT STRESS ANALYSIS OF OPERATORS
REF1419H5W - COOL CONDITION

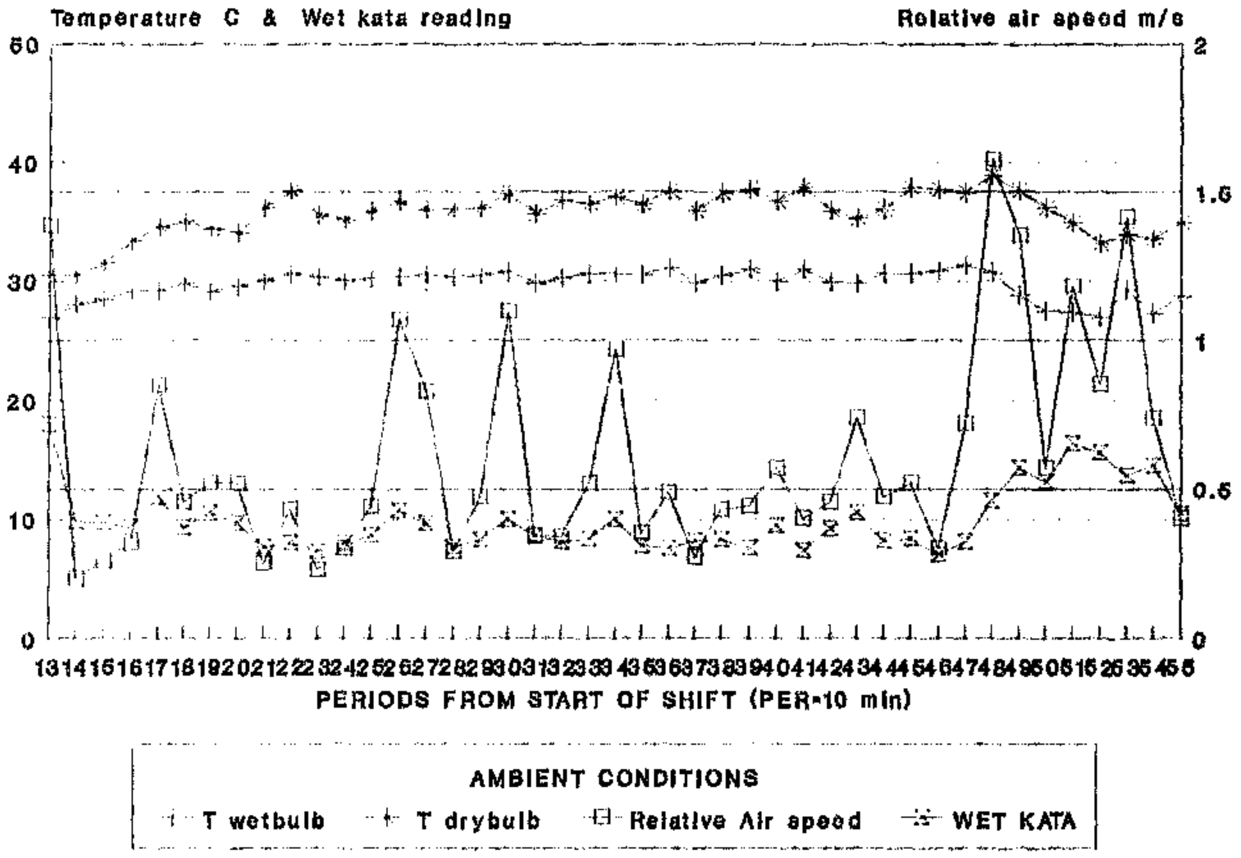
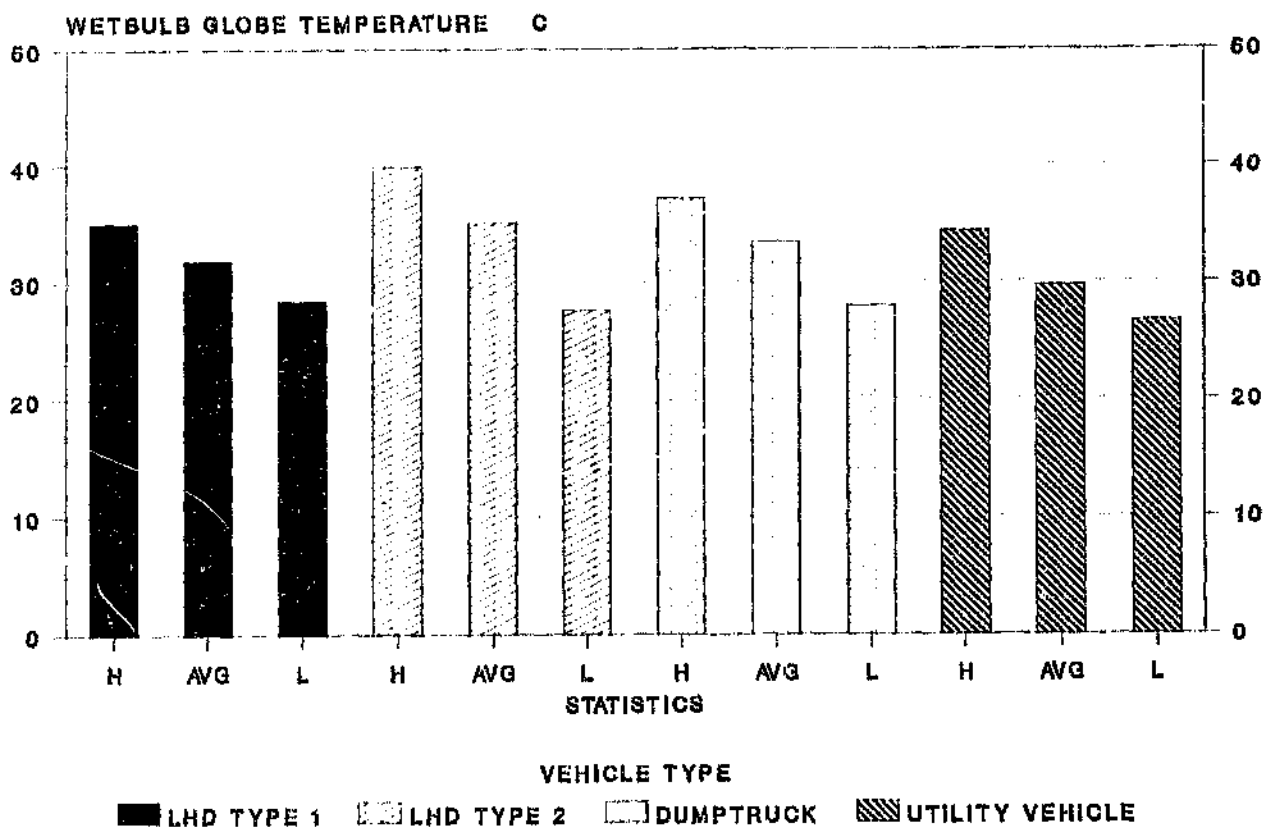


FIG 2.7 N

TEMPERATURE ANALYSIS DRIVERS
WETBULB GLOBE TEMPERATURE



68 FIG 2.7 0

Ergonomics and Controls Effect

- Cabin and seat design need to be evaluated in future research work to improve on the comfort and productivity of the worker. Figure 2.8 show some of these deficiencies.

  - the gap between the drivers's knees and the vehicle wall is in some cases is only 50 mm. This creates extreme discomfort and scorching of the skin, as the wall temperature of the cabin reaches temperatures as high as 65 ^{o} centigrade.

  - the angle of posture of the feet in relation to the footpedals is acute. Unnecessary due exertion is placed on the motorial function of the upper leg and lower back when operating the footpedals. This can be overcome by moving the pedal section by some 150 mm towards the engine compartment. This will improve the action required to operate the controls by making use of a foot-lowerleg motion.

Noise

Noise exposure expressed in Leq or equivalent dose is shown in the table 2.4 below. The analysis was done using a Bruel and Kjaer noise dosimeter.

Operator	Vehicle Type	Leq
LHD	Type 1	115
LHD	Type 2	110
DT		110
UV		98

Table 2.4 - Equivalent noise levels drivers

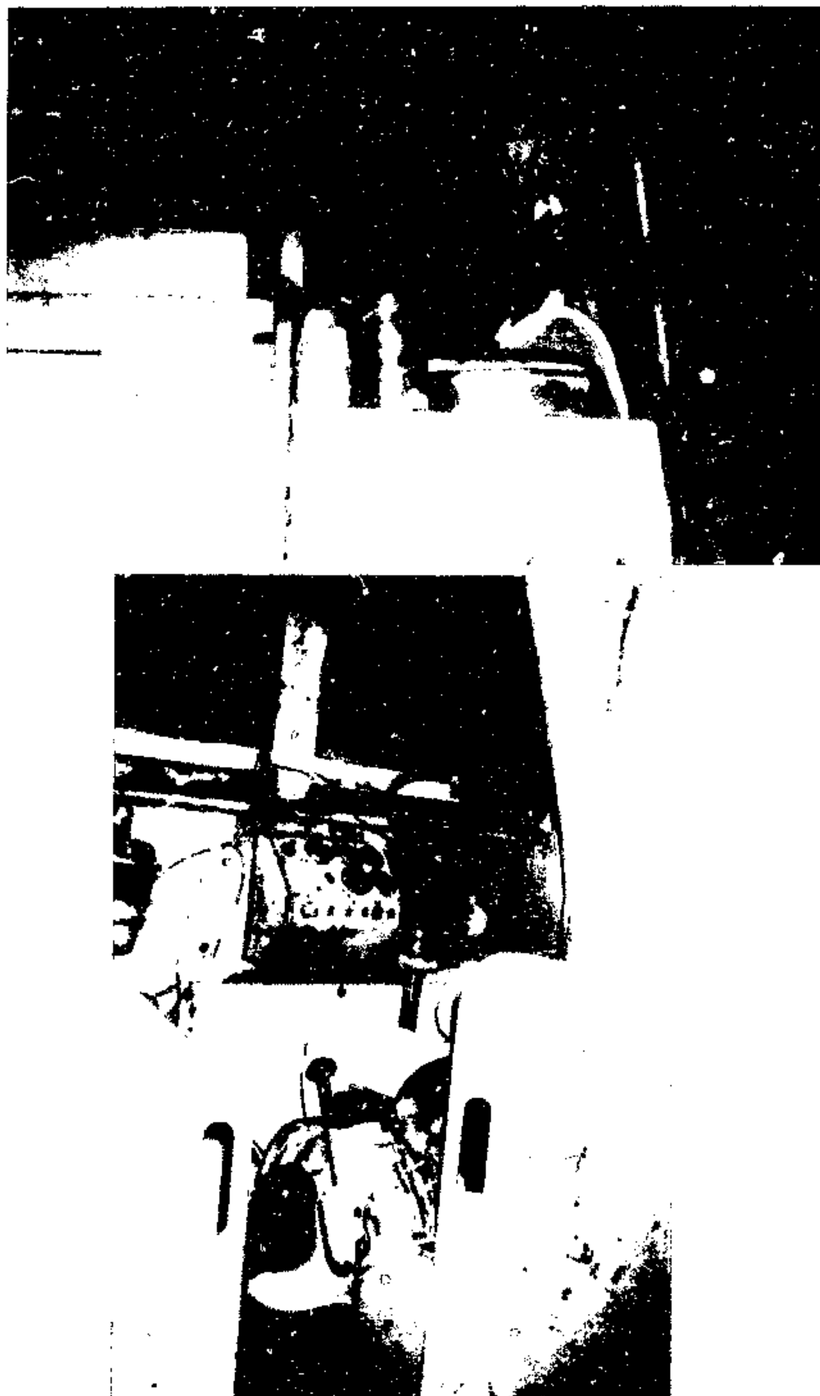


Figure 2.8 - Design of drivers cabin

PROBLEMS

The problems encountered were not insurmountable. The necessity of evaluating these operators in the field is of paramount importance in order to determine an equivalent WBGT and Heat Stress. The ambient temperature ranged from 26,5/33,5 °C to 32,5/40,5 °C for the psychrometric wet and dry bulb temperatures. Tramming / trucking routes spanned several kilometers. The vehicles negotiated difficult terrain and the heat generation by the machine varied considerably.

2.5 DISCUSSION

It was necessary to complete this investigation into the heat stress and other detrimental factors imposed on the diesel powered vehicle operators in a deep, hot mine.

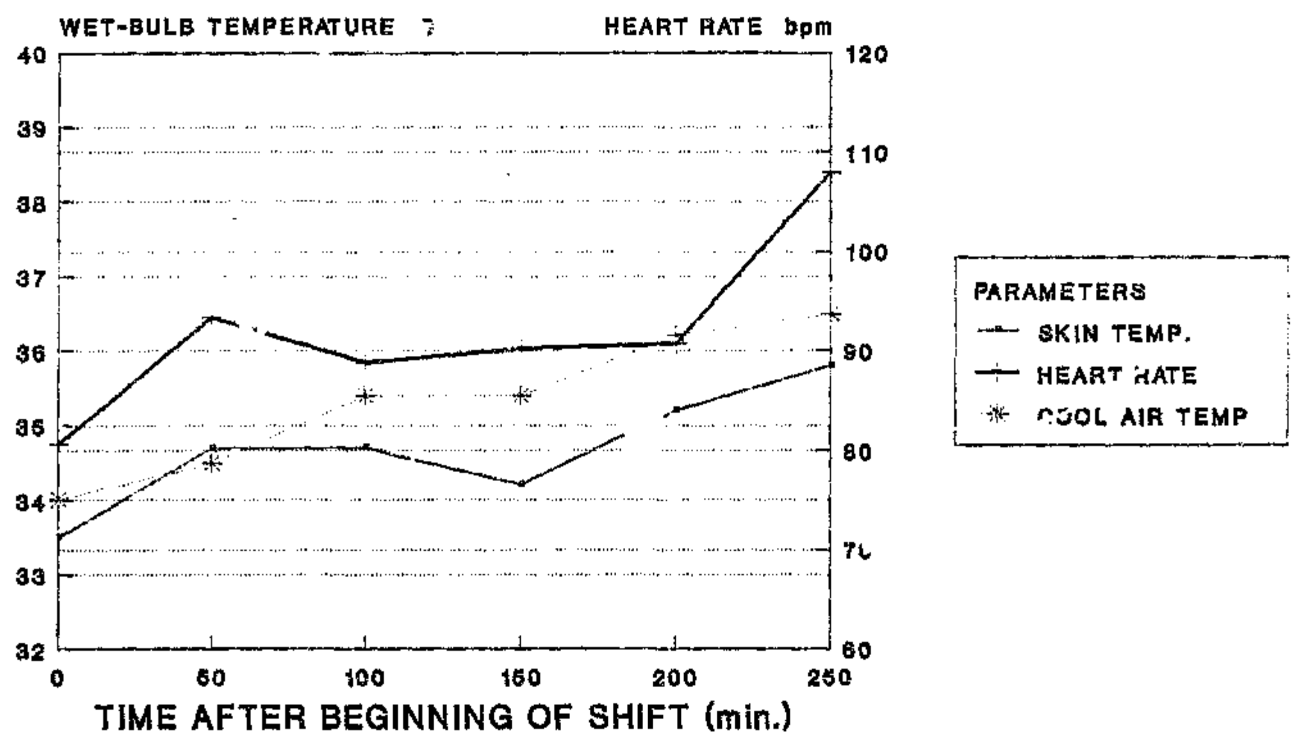
Heat

One of the points not discussed in detail in the aforegoing proceedings are the engineering controls that can be introduced. Preliminary test, using micro climate cooling in the form of an airconditioned air jacket, show promising results. Figure 2.9 and 2.10 show the results obtained from the initial tests.

It is necessary to introduce some controls in the cabin even though the metabolic work rate indicate moderate energy levels.

Future work is necessary to improve on the ergonomics of the cabin.

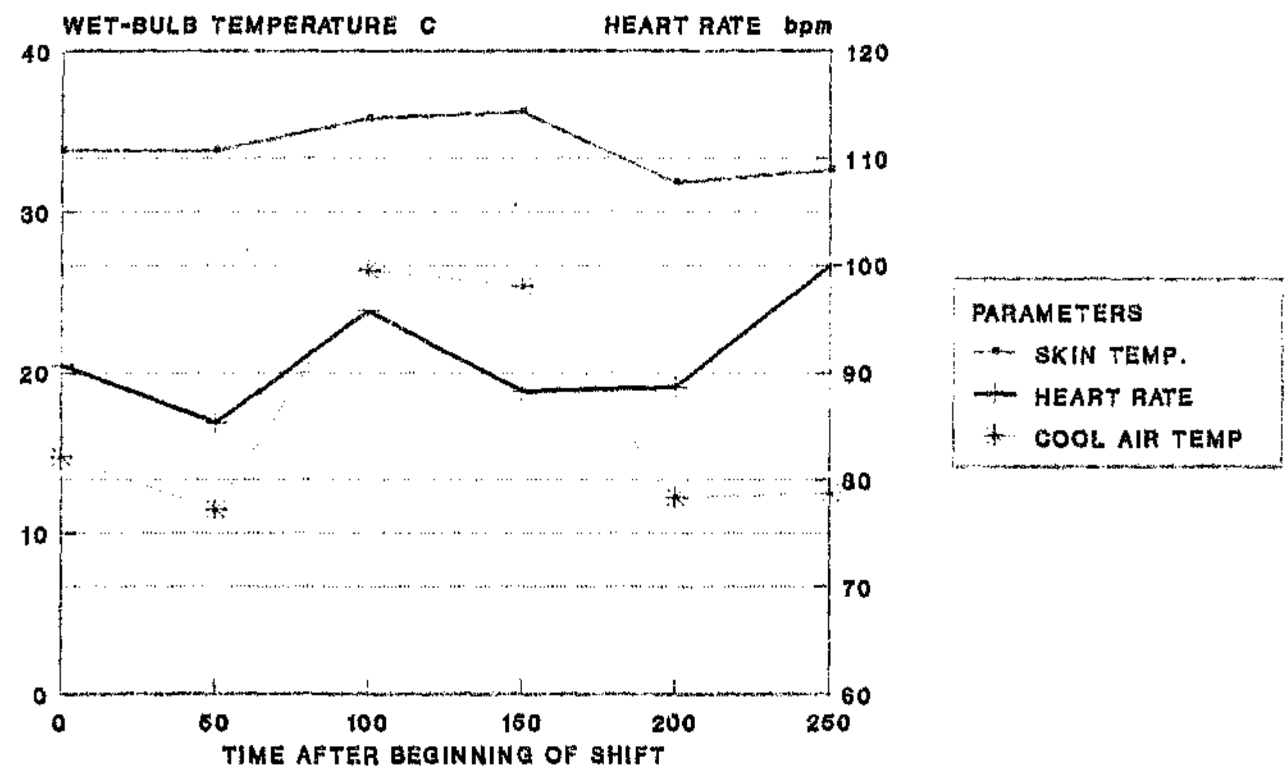
MICRO CLIMATE COOLING TRAILS LHD
COMPARISON OF CERTAIN PARAMETERS
NON COOLING CONDITION



NO PERSONAL AIR CONDITIONER

72 FIG 2.9

MICRO CLIMATE COOLING TRAILS LHD
COMPARISON OF CERTAIN PARMETERS
COOLING CONDITION



PERSONAL AIR CONDITIONER FITTED

7

FIG 2.10

It is necessary to introduce shielding between the driver and the engine air cooling system. The channeling of air from the engine compartment is recommended.

This will allow the compartment to operate under negative pressure conditions with airflow from the cabin to the engine compartment and not visa versa.

Noise

Attenuation of the exhaust ports will also reduce stress factors to which operators are exposed by the installation of a silencer cum diesel particulate filter on the exhaust.

Equivalent noise levels as measured (98 - 115 dBA) far exceed the maximum of 85 dBA for an eight hour shift. It is necessary to ergonomically design a ear attenuator for the use of the driver. If not accepted by the operator, the design is of no value especially under hot humid conditions.

Acclimatisation

It will be necessary to acclimatise operators for work. The problem however lies in the specific parameters employed to acclimatise the driver.

In Trackless Mining, the specific cooling power of the air (at 180 W/m^2 +- 10 W/m^2) rather than the specific airspeed (of 0,4 m/s), wetbulb temperature (of 31,5 °C) and drybulb temperature (equal to twb + 2°C i.e. 32,5°C), is a more accurate indicator of the heat stress of the vehicle operator.

Clothing

If shielding of the body radiant heat cannot be done effectively, the issue of competent heat shielding overalls must be considered. This is necessary as the radiant heat exceeds the critical 35,8°C margin concerning radiant heat exchange.

CONCLUSION

The diesel powered vehicle operators are to be classed in the moderate work rate of $>115\ W/m^2$ $<180\ W/m^2$.

Performance under varying environmental conditions

Heat influences the performance of the driver. Evaluating drivers operating under higher temperatures than 30°C wetbulb, the following was observed and are also shown in figure 2.11 .

The heart rate of operators working under cooler ambient conditions (<30 °C) - also called Mine A - has a higher relative heart rate than their counterparts working in higher temperatures at the same metabolic workrate on Mine B.

The hypothesis is that the workers in mine B have a higher degree of fitness than those working in mine A. Their work capacity has increased due to acclimatization, which inturn develops the cardio/vascular capabilities.

PHYSIOLOGICAL PERFORMANCE
OPERATORS TMMM VEHICLES

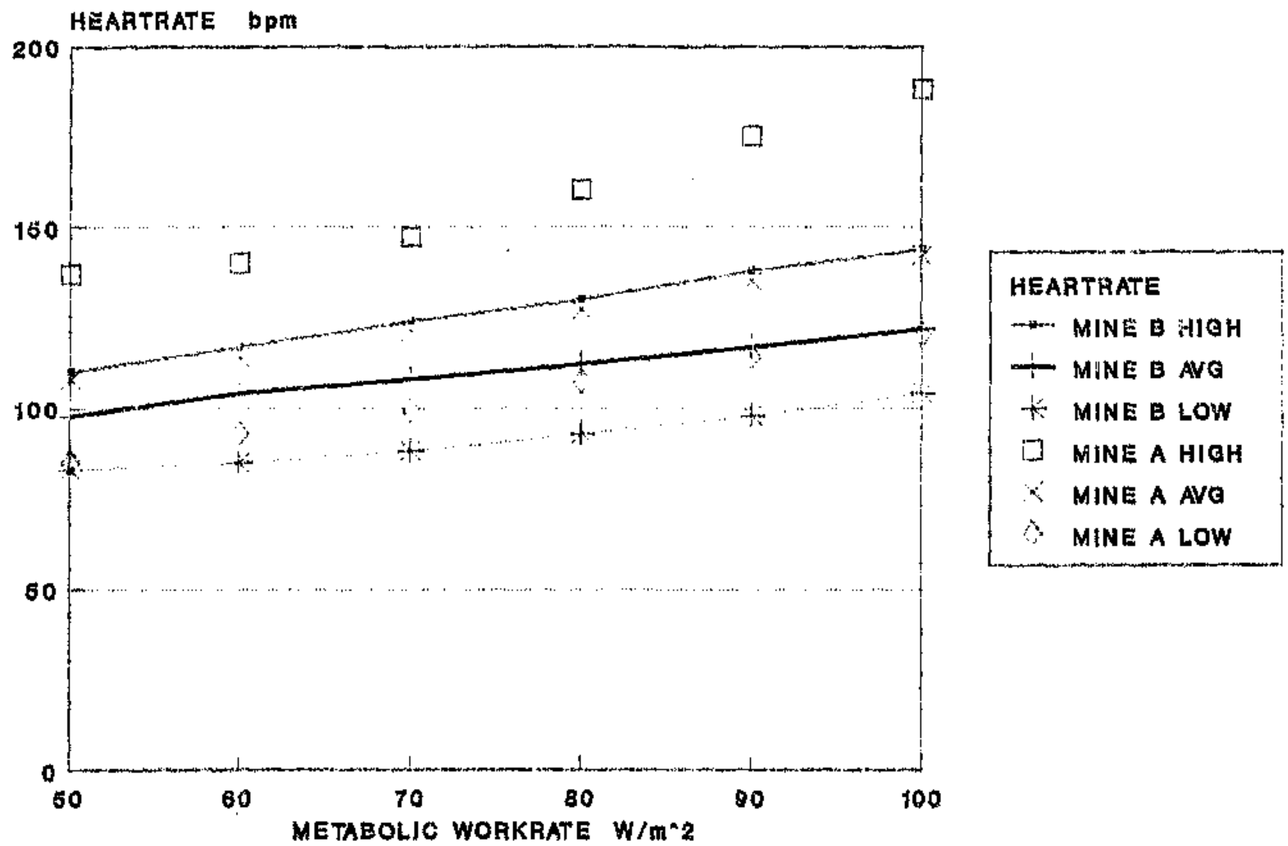


FIG 2.11

The operating costs of these machines were also taken into account. The mining layout for both mines is basically the same. However, the cost figures vary as follows :

Mine	Ton/mach/hour	Utilization	O/cost R/h
A	37,5 & 35,6	87 & 84	132,7& 87,4
B	14,7 & 18,7	85 & 82	150,8& 99,1

LHD & DUMPTRUCK

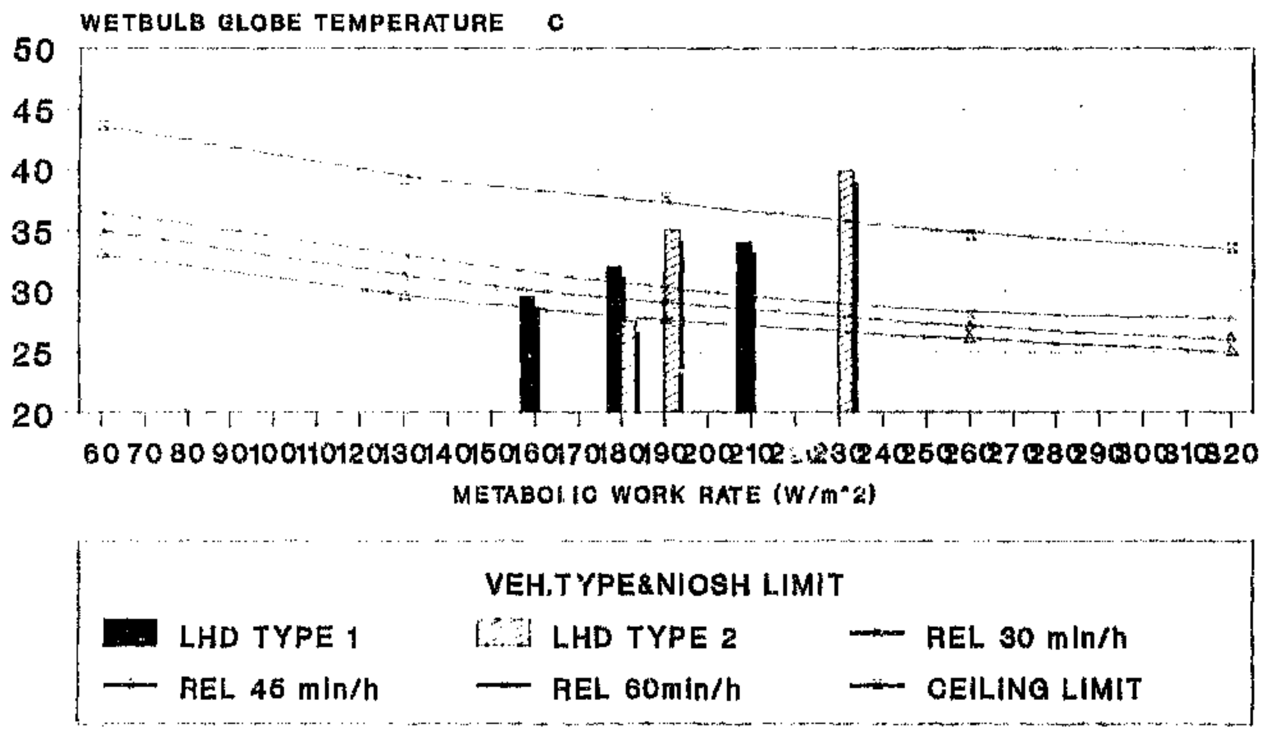
Figures on the left-hand side of each column represents the performance of the LHD's and the other that of the Dumptrucks.

However, operating cost variance cannot only be attributed to ambient conditions. The statement can be made that in view of figure 2.1 (page 30) it can be economically viable to perform ergonomic design improvements on the drivers cabin.

Two graphs (figure 2.12 & 2.13) were drawn to test the operators aganst the NIOSH recommended standard. This standard indicates maximum time exposure limits for workers operating at specific metabolic workrates at a specified wetbulb globe temperature.
In most cases the ambient conditions tied to workrate for the operators tested cover the entire work spectrum. With LHD type 1 drivers, for instance, workrate range between 160 and 210 W/m^2 and they are exposed to a WBGT of between 29 and 34 ^{o} C. In consultation with the standard, as per figure 18, these drivers may not work for a period ranging more than between 50 and 10 minutes per hour before taking a 30 minute rest period !

These two figures indicate that work is required to reduce the influence of the ambient conditions and the accumalative heat effect of the engine heat on the diesel powered vehicle operators.

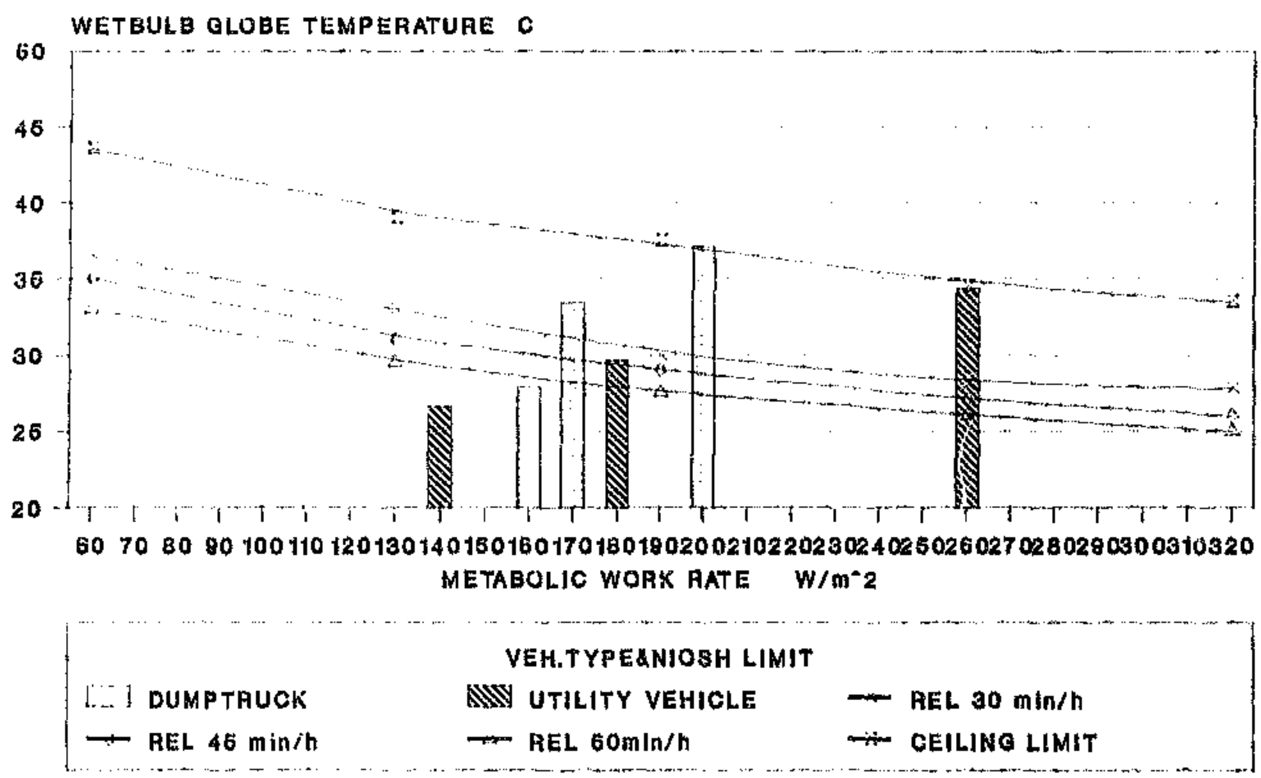
TEMPERATURE ANALYSIS DRIVERS
WETBULB GLOBE TEMPERATURE - DRIVERS AS PER NIOSH EXPOSURES LIMITS



REL = RECOMMENDED EXPOSURE LIMIT
EXPRESSED IN WORK MINUTES / HOUR OF
WORK PERMISSIBLE 79 FIG 2.12

TEMPERATURE ANALYSIS DRIVERS

WETBULB GLOBE TEMPERATURE - DRIVERS AS PER NIOSH EXPOSURES LIMITS



REL = RECOMMENDED EXPOSURE LIMIT
EXPRESSED IN WORK MINUTES / HOUR OF
WORK PERMISSIBLE 80 FIG 2.13

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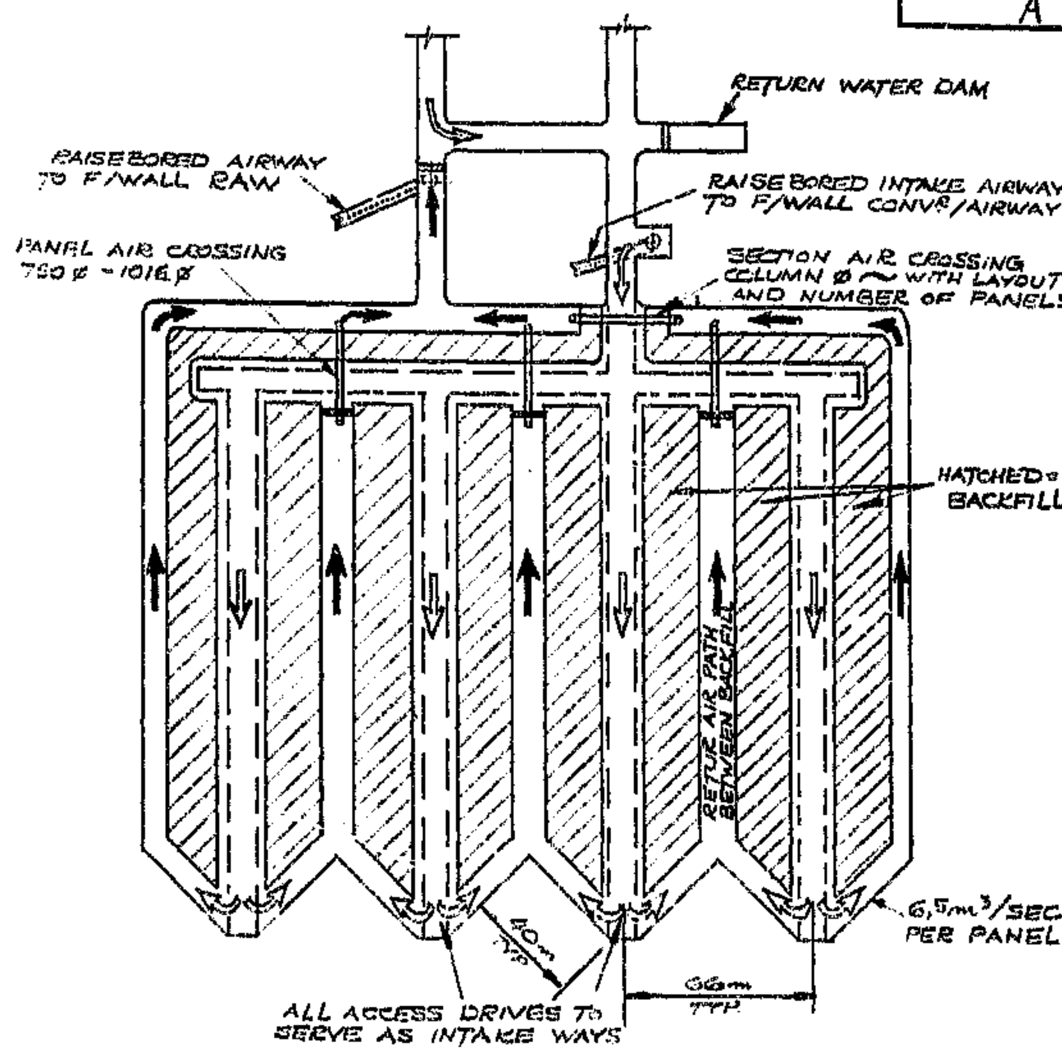
A



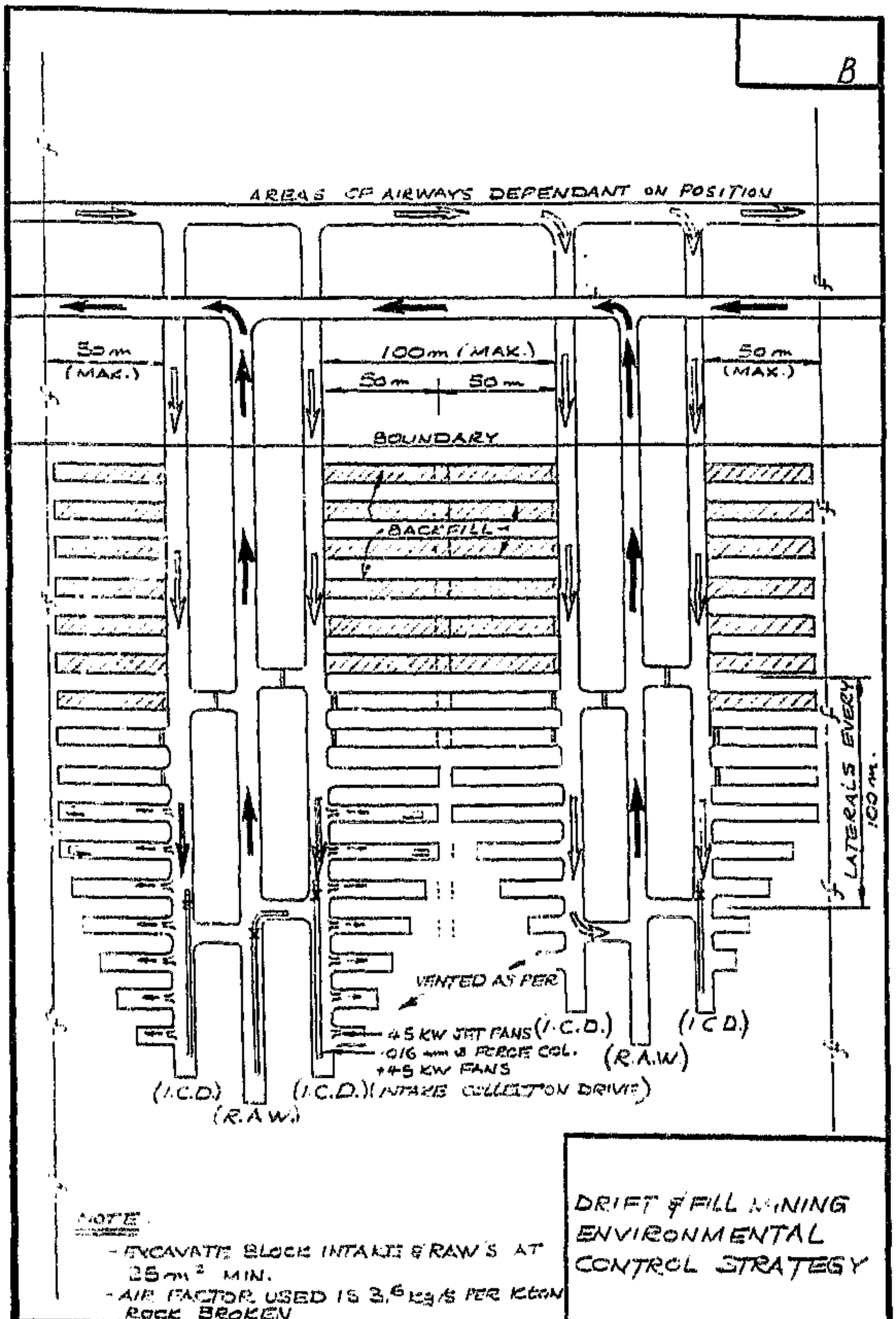
NOTE:

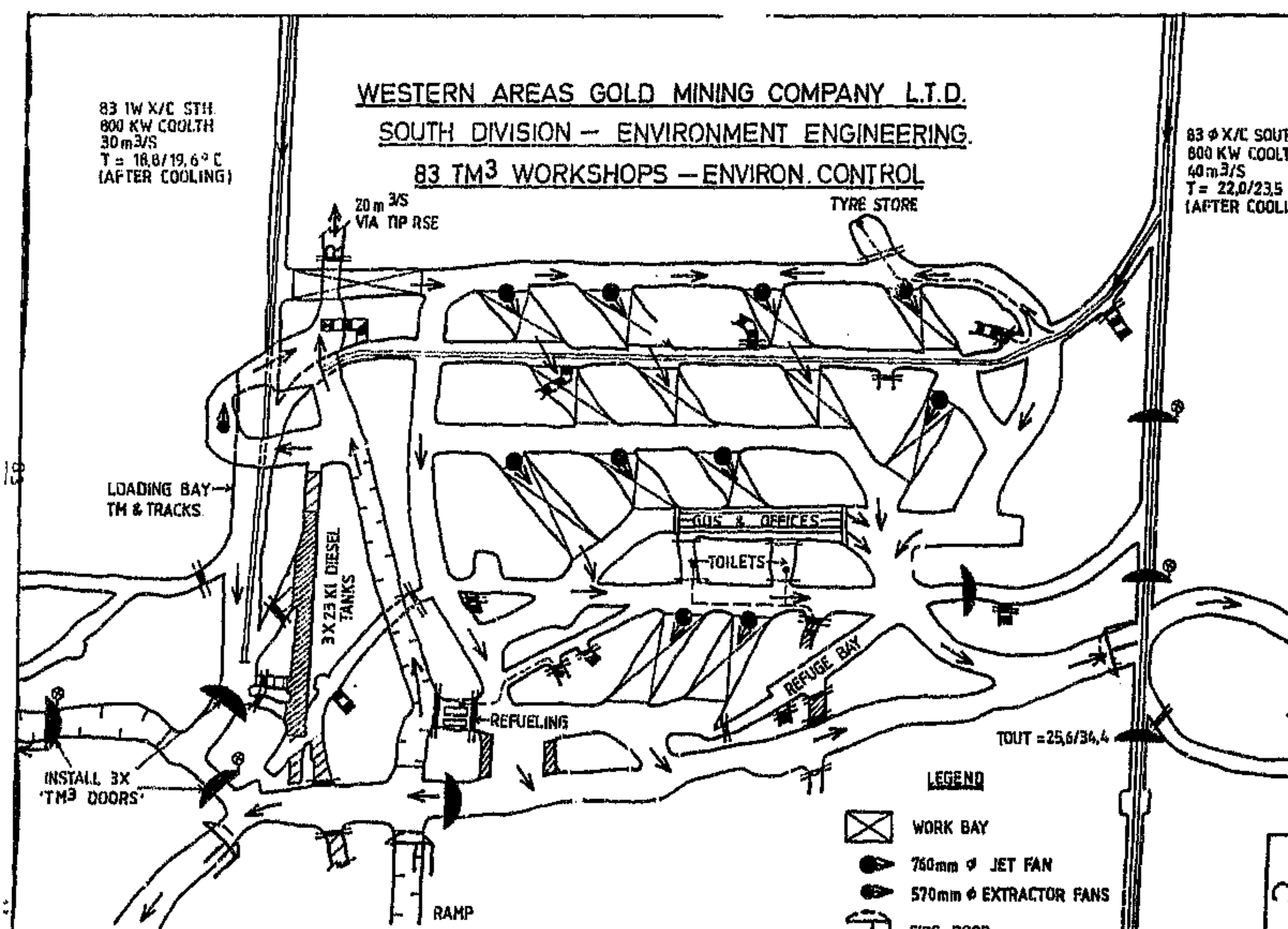
WATER CONTROL: PUMP WATER FROM LOWEST POSITIONS INTO PIPE NETWORK AND DISCHARGE INTO BLOCK'S RETURN WATER DAM TO REDUCE HEAT LOAD

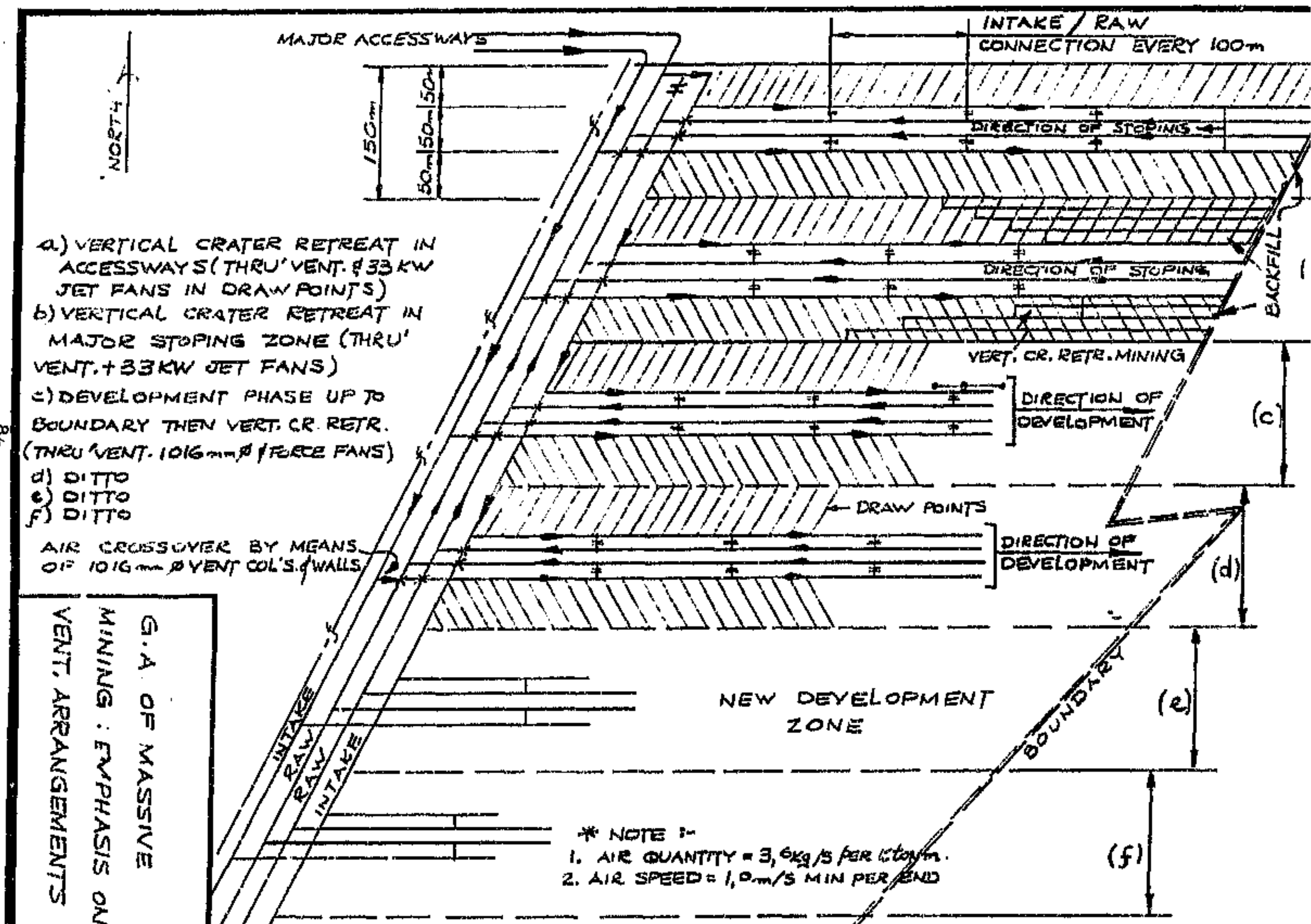
PANEL SPECS: 1,8 m WIDE x 40 m LONG
6,0 m MAX. BACKFILL TO FACE
0,6 m/s AIR SPEED ON FACE

AIR REQUIREMENT: @ 15 m FACE ADV./MONTH (AND 2970 TONS) PLUS 20 % LEAKAGE = 3,4 kg/s PER ktons AND AT 1,8 kg/m³ DENSITY

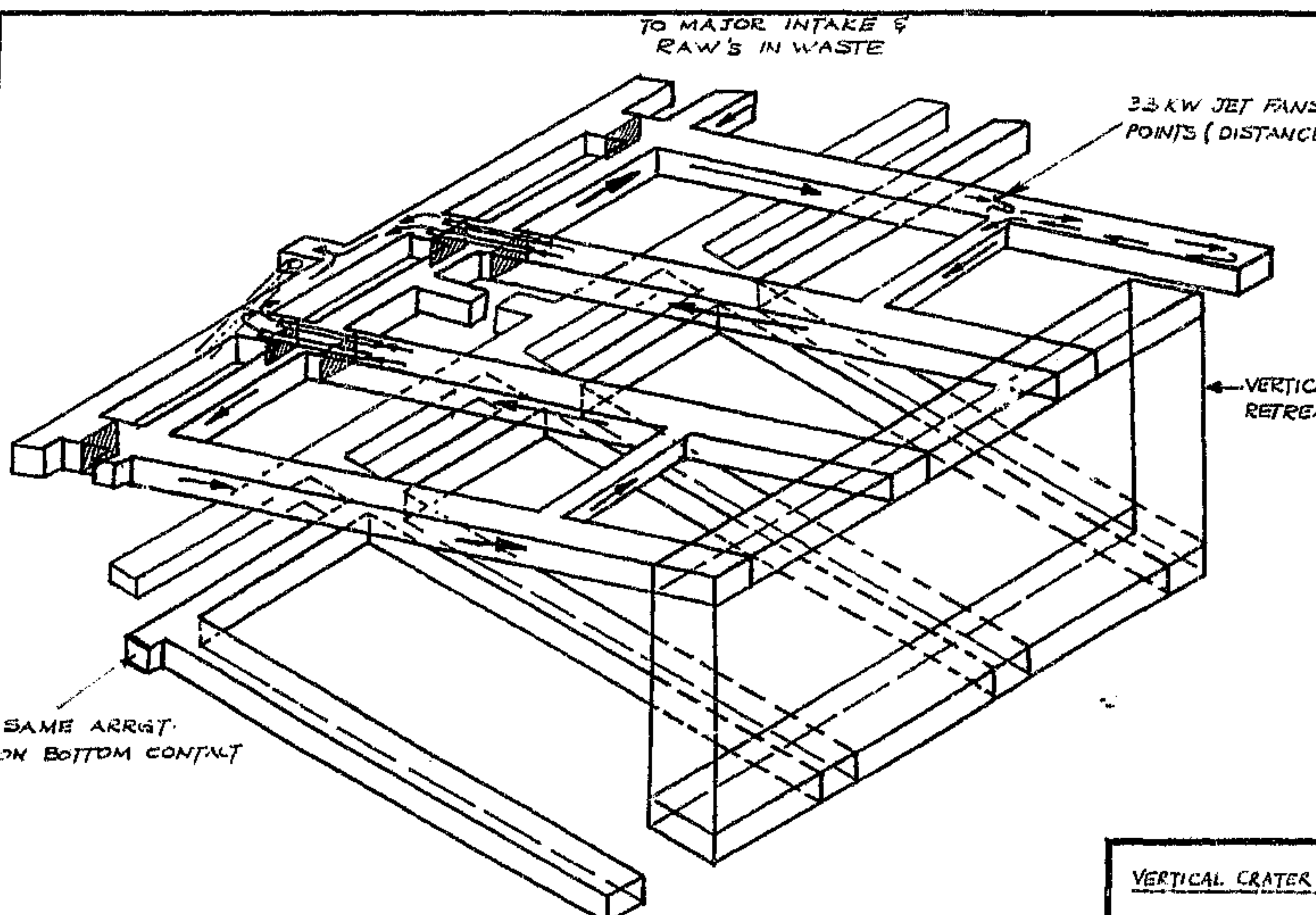
NARROW REEF STOPING ENVIRONMENTAL CONTROL STRATEGY


B
AREAS OF AIRWAYS DEPENDANT ON POSITION
50 m (MAX.)
100 m (MAX.)
50 m
50 m
BOUNDARY
BACKFILL
LATERALS EVERY 100 m.
VENTED AS PER
45 KW JET FANS
.016 m 3 FORCE COL.
+45 KW FANS
(I.C.D.)
(R.A.W.)
(I.C.D.) (INTAKE COLLECTION DRIVE)
NOTE
- EXCAVATE BLOCK INTAKE & RAW'S AT 25 m² MIN.
- AIR FACTOR USED IS 3.6 kg/S PER KtON ROCK BROKEN
DRIFT & FILL MINING ENVIRONMENTAL CONTROL STRATEGY


WESTERN AREAS GOLD MINING COMPANY L.T.D.
SOUTH DIVISION – ENVIRONMENT ENGINEERING.
83 TM3 WORKSHOPS – ENVIRON. CONTROL
83 1W X/C STH.
800 KW COOLTH
30 m3/S
T = 18,8/19,6° C
(AFTER COOLING)
20 m 3/S
VIA TIP RSE
TYRE STORE
83 ϕ X/C SOUTH
800 KW COOLTH
40 m3/S
T = 22,0/23,5
(AFTER COOLIN
LOADING BAY
TM & TRACKS
3 X 23 Kl DIESEL TANKS
GOS & OFFICES
TOILETS
REFUELING
REFUGE BAY
INSTALL 3X
'TM3 DOORS'
RAMP
TOUT =25,6/34,4
LEGEND
WORK BAY
760mm ϕ JET FAN
570mm ϕ EXTRACTOR FANS
FIRE DOOR



MAJOR ACCESSWAYS
NORTH
INTAKE / RAW
CONNECTION EVERY 100m
150m
50m
50m
50m
DIRECTION OF STOPING
DIRECTION OF STOPING
BACKFILL
VERT. CR. RETR. MINING
DIRECTION OF DEVELOPMENT
DIRECTION OF DEVELOPMENT
DRAW POINTS
(c)
(d)
(e)
(f)
a) VERTICAL CRATER RETREAT IN ACCESSWAYS (THRU' VENT. & 33 KW JET FANS IN DRAW POINTS)
b) VERTICAL CRATER RETREAT IN MAJOR STOPING ZONE (THRU' VENT. + 33 KW JET FANS)
c) DEVELOPMENT PHASE UP TO BOUNDARY THEN VERT. CR. RETR. (THRU' VENT. 1016 mm Ø FORCE FANS)
d) DITTO
e) DITTO
f) DITTO
AIR CROSSOVER BY MEANS OF 1016 mm Ø VENT COL'S. & WALLS
NEW DEVELOPMENT ZONE
BOUNDARY
INTAKE
RAW
RAW
INTAKE
* NOTE :-
1. AIR QUANTITY = 3,6 kg/s PER kton/m.
2. AIR SPEED = 1,0 m/s MIN PER END
G.A. OF MASSIVE MINING : EMPHASIS ON VENT. ARRANGEMENTS



VERTICAL CRATER

MAIN ACCESS WA
(REMOVAL)

TEMP.AIR : 28.00 C 35.00
BAR PRESS: 100.15 kPa
kWrated : 144.00 kW
Power : 133.60 (derated)

TRACKLESS MECHANISED MINING METHODS

AT

WESTERN AREAS GOLD MINING COMPANY LIMITED
PERIOD : MARCH 1988 - FEBRUARY 1990

file name: VPER58L APPE
Note : date : 1-9-90 (VEH

shift duration efective at work :
s1 = shift one = morning shift = 6 hrs
sB = blasting time plus re entry = 3 hrs
s2 = shift two = morning shift = 5 hrs
s3 = shift three = morning shift = 6 hrs
on s1, s3 2 hrs are lost for preparation/shif

MACH.NO : LW1486 MACHINE PERFORMANCE ; fuel consumption

MONTH	OPER HRS	FUEL CONS	util s1	util s2	util s3	l/kW/h s1	l/kW/h s2	l/kW/h s3	kWh s1	kWh s2	kWh s3	kWh/kWdr s1	kWh/kWdr s2	kWh/
MRCH 88	183.00	1746.00	64.59	53.82	64.59	0.202	0.243	0.202	102.15	122.59	102.15	0.76	0.92	
APR 88	182.00	1686.00	64.24	53.53	64.24	0.196	0.236	0.196	99.19	119.02	99.19	0.74	0.89	
MAY 88	262.00	1969.00	92.47	77.06	92.47	0.159	0.191	0.159	80.47	96.56	80.47	0.60	0.72	
JUN 88	271.00	2320.00	95.65	79.71	95.65	0.182	0.218	0.182	91.66	109.99	91.66	0.69	0.82	
JUL 88	328.00	2376.00	115.76	96.47	115.76	0.154	0.184	0.154	77.53	93.03	77.53	0.58	0.70	
AUG 88	347.00	3848.00	122.47	102.06	122.47	0.235	0.282	0.235	118.73	142.48	118.73	0.89	1.07	
SEPT 88	184.00	2134.00	64.94	54.12	64.94	0.246	0.295	0.246	124.18	149.01	124.18	0.93	1.12	
OCT 88	249.00	1729.00	87.88	73.24	87.88	0.147	0.177	0.147	74.35	89.22	74.35	0.56	0.67	
NOV 88	256.00	3119.00	90.35	75.29	90.35	0.258	0.310	0.258	130.45	156.54	130.45	0.98	1.17	
DEC 88	123.00	1992.00	43.41	36.18	43.41	0.343	0.412	0.343	173.40	208.08	173.40	1.30	1.56	
JAN 89	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	
FEB 89														
MRCH 89	T 2385.00	22918.00	841.76	701.47	841.76	2.124	2.548	2.124	1072.10	1286.52	1072.10	8.02	9.63	
APR 89	A 238.50	2291.80	84.18	70.15	84.18	0.212	0.255	0.212	107.21	128.65	107.21	0.80	0.96	
MAY 89														
JUN 89														
JUL 89														
AUG 89														
SEPT 89														
OCT 89														
NOV 89														
DEC 89														
JAN 90														
FEB 90														

remarks:
utilization is taken as total hours operating split over the three shifts on a ratio basis
fuel consumption expressed at deration due to ambient conditions .

TEMP.AIR : 28.00 C 35.00
BAR PRESS: 100.15 kPa
kWrated : 144.00 kW
Power : 133.60 (derated)

TRACKLESS MECHANISED MINING METHODS
AT
WESTERN AREAS GOLD MINING COMPANY LIMITED
PERIOD : MARCH 1988 - FEBRUARY 1990

file name: VPER58L
date : 1-9-90

APPE
(VEH

Note :
shift duration efective at work :
s1 = shift one = morning shift = 6 hrs
sB = blasting time plus re entry = 3 hrs
s2 = shift two = morning shift = 5 hrs
s3 = shift three = morning shift = 6 hrs
on s1, s3 2 hrs are lost for preparation/shif

MACH.NO : LW2263 MACHINE PERFORMANCE : fuel consumption :

MONTH	OPER HRS	FUEL CONS	util s1	util s2	util s3	l/kW/h s1	l/kW/h s2	l/kW/h s3	kWh s1	kWh s2	kWh s3	kWh/kWdr s1	kWh/kWdr s2	kWh/
MRCH 88	280.00	3682.00	98.82	82.35	98.82	0.223	0.268	0.223	140.80	168.96	140.80	0.84	1.01	
APR 88	250.00	2361.00	88.24	73.53	88.24	0.162	0.194	0.162	101.97	122.37	101.97	0.61	0.73	
MAY 88	281.00	2499.00	99.18	82.65	99.18	0.151	0.181	0.151	96.22	114.26	95.22	0.57	0.68	
JUN 88	318.00	4796.00	112.24	93.53	112.24	0.256	0.307	0.256	161.48	193.78	161.48	0.97	1.16	
JUL 88	339.00	4403.00	119.65	99.71	119.65	0.220	0.264	0.220	139.06	166.88	139.06	0.83	1.00	
AUG 88	368.00	5093.00	129.88	108.24	129.88	0.235	0.282	0.235	148.18	177.82	148.18	0.89	1.06	
SEPT 88	245.00	3316.00	86.47	72.06	86.47	0.230	0.276	0.230	144.92	173.90	144.92	0.87	1.04	
OCT 88	372.00	4112.00	131.29	109.41	131.29	0.188	0.225	0.188	118.35	142.02	118.35	0.71	0.85	
NOV 88	252.00	4786.00	88.94	74.12	88.94	0.322	0.387	0.322	203.35	244.02	203.35	1.22	1.46	
DEC 88	341.00	5509.00	120.35	100.29	120.35	0.274	0.329	0.274	172.98	207.57	172.98	1.04	1.24	
JAN 89	256.00	3487.00	90.35	75.29	90.35	0.231	0.277	0.231	145.84	175.01	145.84	0.87	1.05	
FEB 89	180.00	2472.00	63.53	52.94	63.53	0.233	0.280	0.233	147.04	176.45	147.04	0.88	1.06	
MRCH 89	155.00	1332.00	54.71	45.59	54.71	0.146	0.175	0.146	92.01	110.41	92.01	0.55	0.66	
APR 89	139.00	1223.00	49.06	40.88	49.06	0.149	0.179	0.149	94.21	113.05	94.21	0.56	0.68	
MAY 89	208.00	2641.00	73.41	61.18	73.41	0.215	0.259	0.215	135.95	163.14	135.95	0.81	0.98	
JUN 89	237.00	3878.00	83.65	69.71	83.65	0.278	0.333	0.278	175.20	210.24	175.20	1.05	1.26	
JUL 89	269.00	3091.00	94.94	79.12	[illegible].94	0.195	0.234	0.195	123.03	147.64	123.03	0.74	0.88	
AUG 89	250.00	5075.00	88.24	73.53	88.24	0.344	0.413	0.344	217.35	260.82	217.35	1.30	1.56	
SEPT 89	T 4460.00	60094.00	1574.12	1311.76	1574.12	3.829	4.594	3.829	2416.13	2899.36	2416.13	14.47	17.36	
OCT 89	A 263.33	3543.11	92.94	77.45	92.94	0.225	0.270	0.225	142.05	170.46	142.05	0.85	1.02	
NOV 89														
DEC 89														
JAN 90														
FEB 90														

remarks:
utilization is taken as total hours operating split over the three shifts on a ratio basis
fuel consumption expressed at deration due to ambient conditions .

TEMP.AIR : 28.00 C 35.00
BAR PRESS: 100.15 kPa
kWrated : 144.00 kW
Power : 133.60 (derated)

TRACKLESS MECHANISED MINING METHODS
AT
WESTERN AREAS GOLD MINING COMPANY LIMITED
PERIOD : MARCH 1988 - FEBRUARY 1990

file name: VPER58L APPE
date : 1-9-90 (VEH

Note :
shift duration efective at work :
s1 = shift one = morning shift = 6 hrs
sB = blasting time plus re entry = 3 hrs
s2 = shift two = morning shift = 5 hrs
s3 = shift three = morning shift = 6 hrs
on s1, s3 2 hrs are lost for preparation/shift

MACH.NO : UG1144 MACHINE PERFORMANCE : fuel consumption :

MONTH	OPER HRS	FUEL CONS	util s1	util s2	util s3	l/kW/h s1	l/kW/h s2	l/kW/h s3	kWh s1	kWh s2	kWh s3	kWh/kWdr s1	kWh/kWdr s2	kWh/k
MRCH 88	237.00	923.00	83.65	69.71	83.65	0.251	0.301	0.251	41.70	50.04	41.70	0.95	1.14	
APR 88	97.00	809.00	34.24	28.53	34.24	0.537	0.644	0.537	89.30	107.16	89.30	2.03	2.44	
MAY 88	229.00	706.00	80.32	67.35	80.82	0.199	0.238	0.199	33.01	39.61	33.01	0.75	0.90	
JUN 88	325.00	1024.00	114.71	95.59	114.71	0.203	0.243	0.203	33.74	40.48	33.74	0.77	0.92	
JUL 88	210.00	743.00	74.12	61.76	74.12	0.228	0.273	0.228	37.88	45.46	37.88	0.86	1.03	
AUG 88	287.00	1830.00	101.29	84.41	101.29	0.411	0.493	0.411	68.27	81.92	68.27	1.55	1.86	
SEPT 88	223.00	1050.00	78.71	65.59	78.71	0.303	0.364	0.303	50.41	60.50	50.41	1.15	1.37	
OCT 88	182.00	838.00	64.24	53.53	64.24	0.296	0.356	0.296	49.30	59.16	49.30	1.12	1.34	
NOV 88	303.00	1110.00	106.94	89.12	106.94	0.236	0.283	0.236	39.22	47.07	39.22	0.89	1.07	
DEC 88	334.00	1251.00	117.88	98.24	117.88	0.241	0.289	0.241	40.10	48.12	40.10	0.91	1.09	
JAN 89	252.00	613.00	88.94	74.12	88.94	0.157	0.188	0.157	26.05	31.25	26.05	0.59	0.71	
FEB 89	197.00	480.00	69.53	57.94	69.53	0.157	0.188	0.157	26.09	31.31	26.09	0.59	0.71	
MRCH 89	203.00	624.00	71.65	59.71	71.65	0.198	0.238	0.198	32.91	39.49	32.91	0.75	0.90	
APR 89	75.00	331.00	26.47	22.06	26.47	0.284	0.341	0.284	47.25	56.70	47.25	1.07	1.29	
MAY 89	160.00	1186 00	56.47	47.06	56.47	0.477	0.573	0.477	79.37	95.24	79.37	1.80	2.16	
JUN 89	172.00	795.00	60.71	50.59	60.71	0.298	0.357	0.298	49.49	59.39	49.49	1.12	1.35	
JUL 89	288.00	948.00	101.65	84.71	101.65	0.212	0.254	0.212	35.24	42.29	35.24	0.80	0.96	
AUG 89	279.00	1047.00	98.47	82.06	98.47	0.242	0.290	0.242	40.18	48.22	40.18	0.91	1.10	
SEPT 89	T 4053.00	16308.00	1430.47	1192.06	1430.47	4.929	5.914	4.929	819 51	983.41	819.51	18.63	22.35	
OCT 89	A 225.17	906.00	79.47	66.23	79.47	0.274	0.329	0.274	45.53	54.63	45.53	1.03	1.24	
NOV 89														
DEC 89														
JAN 90														
FEB 90														

remarks:
utilization is taken as total hours operating split over the three shifts on a ratio basis
fuel consumption expressed at deration due to ambient conditions .

TEMP.AIR : 28.00 C 35.00
BAR PRESS: 100.15 kPa
kWrated : 144.00 kW
Power : 133.60 (derated)

TRACKLESS MECHANISED MINING METHODS
AT
WESTERN AREAS GOLD MINING COMPANY LIMITED
PERIOD : MARCH 1988 - FEBRUARY 1990

file name: VPER58L APPENI
date : 1-9-90 (VEHPI

Note :
shift duration efective at work :
s1 = shift one = morning shift = 6 hrs
s8 = blasting time plus re entry = 3 hrs
s2 = shift two = morning shift = 5 hrs
s3 = shift three = morning shift = 6 hrs
on s1, s3 2 hrs are lost for preparation/shift

MACH.NO : LW1454 MACHINE PERFORMANCE : fuel consumption :

MONTH	OPER HRS	FUEL CONS	util s1	util s2	util s3	l/kW/h s1	l/kW/h s2	l/kW/h s3	kWh s1	kWh s2	kWh s3	kWh/kWdr s1	kWh/kWdr s2	kWh/kl
MRCH 88	0.00	0.00	0.00	0.00	0.00	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
APR 88	0.00		0.00	0.00	0.00	ERP	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
MAY 88	0.00		0.00	0.00	0.00	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
JUN 88	0.00		0.00	0.00	0.00	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
JUL 88	0.00		0.00	0.00	0.00	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
AUG 88	0.00		0.00	0.00	0.0C	ERR	ERR	ERR	ERR	ERR	ERP	ERR	ERR	
SEPT 88	0.00		0.00	0.00	0.00	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
OCT 88	0.00		0.00	0.00	0.00	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
NOV 88	125.00	1542.00	44.12	36.76	44.12	0.263	0.315	0.263	132.08	158.50	132.08	0.99	1.19	
DEC 88	255.00	2315.00	90.00	75.00	90.00	0.193	0.232	0.193	97.20	116.64	97.20	0.73	0.88	
JAN 89	82.00	542.00	28.94	24.12	28.94	0.141	0.169	0.141	70.77	84.92	70.77	0.53	0.64	
FEB 89	143.00	1254.00	50.47	42.06	50.47	0.187	0.224	0.187	93.89	112.67	93.89	0.71	0.85	
MRCH 89	250.00	1891.00	88.24	73.53	88.24	0.161	0.193	0.161	80.99	97.18	80.99	0.61	0.73	
APR 89	191.00	1123.00	67.41	56.18	67.41	0.125	0.150	0.125	62.95	75.54	62.95	0.47	0.57	
MAY 89	264.00	953.00	93.18	77.65	93.18	0.077	0.092	0.077	38.65	46.38	38.65	0.29	0.35	
JUN 89	267.00	1797.00	94.24	78.53	94.24	0.143	0.172	0.143	72.06	86.47	72.06	0.54	0.65	
JUL 89	283.00	2987.00	99.88	83.24	99.88	0.225	0.270	0.225	113.01	135.61	113.01	0.85	1.02	
AUG 89	311.00	1904.00	109.76	91.47	109.76	0.130	0.157	0.130	65.55	78.66	65.55	0.49	0.59	
SEPT 89	333.00	2332.00	117.53	97.94	117.53	0.149	0.179	0.149	74.98	89.98	74.98	0.56	0.68	
OCT 89	324.00	2063.00	114.35	95.29	114.35	0.136	0.163	0.136	68.17	81.81	68.17	0.51	0.62	
NOV 89	285.00	2197.00	100.59	83.82	100.59	0.164	0.197	0.164	82.54	99.04	82.54	0.62	0.74	
DEC 89	240.00	2232.00	84.71	70.59	84.71	0.198	0.238	0.198	99.57	119.49	99.57	0.75	0.90	
JAN 90	208.00	2664.00	73.41	61.18	73.41	0.273	0.327	0.273	137.13	164.56	137.13	1.03	1.24	
FEB 90	141.00	1265.00	49.76	41.47	49.76	0.191	0.229	0.191	96.06	115.27	96.06	0.72	0.87	
	T 3702.00	29061.00	1306.59	1088.82	1306.59	2.757	3.308	2.757	* 1385.61	1662.74	1385.61	10.42	12.50	
	A 454.94	3536.25	160.57	133.81	160.57	0.328	0.394	0.328	* 164.95	197.54	164.95	1.24	1.49	

TEMP.AIR : 28.00 C 35.00
BAR PRESS: 100.15 kPa
kWrated : 144.00 kW
Power : 133.60 (derated)

TRACKLESS MECHANISED MINING METHODS
AT
WESTERN AREAS GOLD MINING COMPANY LIMITED
PERIOD : MARCH 1988 - FEBRUARY 1990

file name: VPER58L APPE
Note : date : 1-9-90 (VEH

shift duration efective at work ·
s1 = shift one = morning shift = 6 hrs
sB = blasting time plus re entry = 3 hrs
s2 = shift two = morning shift = 5 hrs
s3 = shift three = morning shift = 6 hrs
on s1,s3 looses 2 hrs and no drill. takes pla

MACH.NO : DA 1040 MACHINE PERFORMANCE — fuel consumption

MONTH	OPER HRS	FUEL CONS	util s1	util s2	util s3	l/kW/h s1	l/kW/h s2	l/kW/h s3	kWh s1	kWh s2	kWh s3	kWh/kWdr s1	kWh/kWdr s2	kWh/
MRCH 88	119.00	332.00	64.91	0.00	54.09	0.111	ERR	0.133	29.87	ERR	29.87	0.65	ERR	
APR 88	99.00	180.00	34.94	0.00	34.94	0.112	ERR	0.112	30.09	ERR	25.07	0.65	ERR	
MAY 88	73.00	182.00	25.76	0.00	25.76	0.154	ERR	0.154	41.25	ERR	34.36	0.90	ERR	
JUN 88	89.00	279.00	31.41	0.00	31.41	0.193	ERR	0.193	51.87	ERR	43.23	1.13	ERR	
JUL 88	116.00	230.00	40.94	0.00	40.94	0.122	ERR	0.122	32.81	ERR	27.34	0.71	ERR	
AUG 88	73.00	644.00	25.76	0.00	25.76	0.543	ERR	0.543	145.98	ERR	121.65	3.17	ERR	
SEPT 88	131.00	468.00	46.24	0.00	46.24	0.220	ERR	0.220	59.11	ERR	49.26	1.29	ERR	
OCT 88	128.00	316.00	45.18	0.00	45.18	0.152	ERR	0.152	40.85	ERR	34.04	0.89	ERR	
NOV 88	194.00	261.00	68.47	0.00	68.47	0.083	ERR	0.083	22.26	ERR	18.55	0.48	ERR	
DEC 88	169.00	428.00	59.65	0.00	59.65	0.156	ERR	0.156	41.91	ERR	34.92	0.91	ERR	
JAN 89	140.00	366.00	49.41	0.00	49.41	0.161	ERR	0.161	43.26	ERR	36.05	0.94	ERR	
FEB 89	130.00	428.00	45.88	0.00	45.88	0.203	ERR	0.203	54.48	ERR	45.40	1.18	ERR	
MRCH 89	T 1191.00	3320.00	443.2[illegible]	0.00	432.44	1.846	ERR	1.869	496.00	ERR	418.31	10.78	ERR	
APR 89	A 119.10	332.00	44.33	0.00	43.24	0.185	ERR	0.187	49.60	ERR	41.83	1.08	ERR	
MAY 89														
JUN 89														
JUL 89														
AUG 89														
SEPT 89														
OCT 89														
NOV 89														
DEC 89														
JAN 90														
FEB 90														

REMARKS :
NOT ALL VEHICLES HAVE BEEN EVALUATED - THE FOLLOWING SUMMARY IS NECESSARY OF THE REMAINDER OF UNITS:

TEMP.AIR : 28.00 C 35.00
BAR PRESS: 100.15 kPa
kWrated : 144.00 kW
Power : 133.60 (derated)

TRACKLESS MECHANISED MINING METHODS

AT

WESTERN AREAS GOLD MINING COMPANY LIMITED
PERIOD : MARCH 1980 - FEBRUARY 1990

file name: VPER58L APP
date : 1-9-90 (V

Note :

shift duration efective at work :
s1 = shift one = morning shift = 6 hrs
sB = blasting time plus re entry = 3 hrs
s2 = shift two = morning shift = 6 hrs
s3 = shift three = morning shift = 6 hrs

MACH.NO : others — MACHINE PERFORMANCE — fuel consumption — HEAT

MONTH	OPER HRS	FUEL CONS	util s1	util s2	util s3	l/kW/h s1	l/kW/h s2	l/kW/h s3	kWh s1	kWh s2	kWh s3	kWh/kWdr s1	kWh/kWdr s2	kWh
MRCH 88	378.00	386.00	133.41	111.18	133.41	0.014	0.016	0.014	10.93	10.93	10.93	0.06	0.05	
APR 88	408.00	559.00	172.24	143.53	172.24	0.021	0.025	0.021	12.26	12.26	12.26	0.09	0.09	
MAY 88	433.00	1041.00	152.82	127.35	152.02	0.043	0.052	0.043	25.74	25.74	25.74	0.16	0.16	
JUN 88	574.00	912.00	202.59	168.82	202.59	0.029	0.034	0.029	17.01	17.01	17.01	0.11	0.11	
JUL 88	600.00	2200.00	211.76	176.47	211.76	0.066	0.079	0.066	39.26	39.26	39.26	0.25	0.25	
AUG 88	465.00	1112.00	164.12	136.76	164.12	0.043	0.052	0.043	25.60	25.60	25.60	0.16	0.16	
SEPT 88	604.00	634.00	213.18	177.65	213.18	0.019	0.023	0.019	11.24	11.24	11.24	0.07	0.07	
OCT 88	604.90	535.00	213.49	177.91	213.49	0.022	0.027	0.022	9.47	9.47	9.47	0.08	0.08	
NOV 88	492.70	1027.00	173.89	144.91	173.89	0.037	0.045	0.037	22.32	22.32	22.32	0.14	0.14	
DEC 88	516.20	686.00	182.19	151.82	182.19	0.018	0.021	0.018	14.23	14.23	14.23	0.07	0.07	
JAN 89	265.50	614.00	93.71	78.09	93.71	0.031	0.037	0.031	24.76	24.76	24.76	0.12	0.12	
FEB 89	246.00	508.00	86.82	72.36	86.82	0.052	0.063	0.052	22.11	22.11	22.11	0.20	0.20	
MRCH 89	384.00	1110.00	135.53	112.94	135.53	0.057	0.068	0.073	30.95	30.95	30.95	0.22	0.22	
APR 89	484.00	1064.00	170.82	142.35	170.82	0.071	0.085	0.056	23.54	23.54	23.54	0.27	0.27	
MAY 89	543.00	1015.00	191.65	159.71	191.65	0.060	0.072	0.047	20.01	20.01	20.01	0.23	0.23	
JUN 89	353.00	722.00	124.59	103.82	124.59	0.132	0.158	0.052	21.90	21.90	21.90	0.50	0.50	
JUL 89	45.00	80.00	15.88	13.24	15.88	0.126	0.151	0.050	20.94	20.94	20.94	0.48	0.48	
AUG 89	T 7476.30	14213.00	2638.69	2198.91	2638.69	0.84	1.01	0.67	352.28	352.28	352.28	3.17	3.17	
SEPT 89	A 439.702	836.059	155.217	129.348	155.217	0.049	0.059	0.040	20.722	20.722	20.722	0.187	0.187	
OCT 89														
NOV 89														
DEC 89														
JAN 90														
FEB 90														

TEMP.AIR : 28.00 C 35.00
BAR PRESS: 100.15 kPa
kWrated : 144.00 kW
Power : 123.65 (derated)

TRACKLESS MECHANISED MINING METHODS
AT
WESTERN AREAS GOLD MINING COMPANY LIMITED
PERIOD : MARCH 1988 - FEBRUARY 1990

file name: VPERSGL date: 1-9-00

APPENDIX F (VEHPERFSGL)

Note : shift duration efective at work :
s1 = shift one = morning shift = 6 hrs
s0 = blasting time plus re entry = 3 hrs
s2 = shift two = morning shift = 5 hrs
s3 = shift three = morning shift = 6 hrs

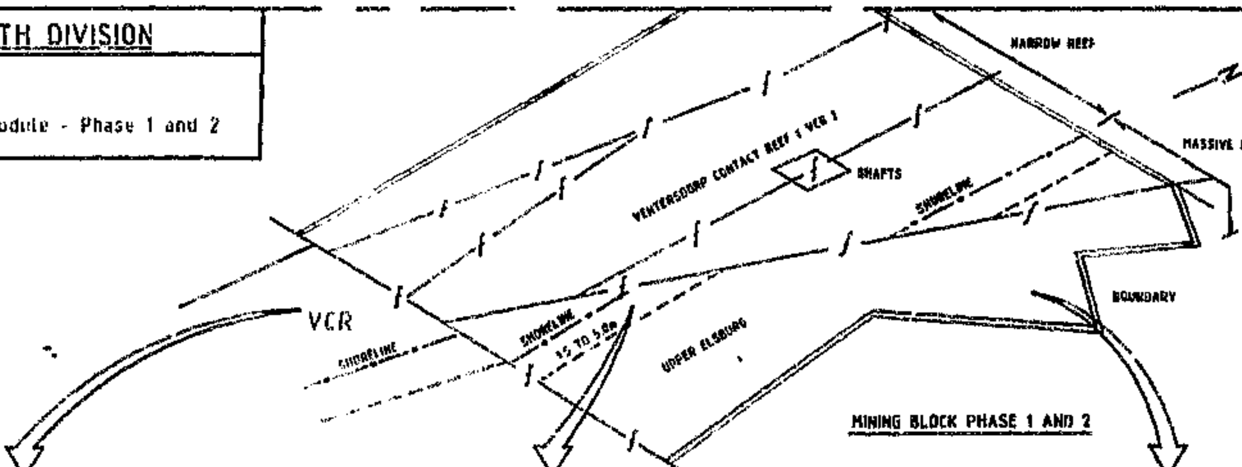
MACH.NO :

MONTH	TOTAL OPER HRS	MACHINE PERFORMANCE FUEL CONS	util s1	util s2	util s3	fuel consumption l/kWh s1	l/kWh s2	l/kWh s3	HEAT kWh s1	kWh s2	kWh s3	kWh/kWdr s1	kWh/kWdr s2	kWh/kWdr s3	PRODUCTION RELATED FIGURES TONNES /M	t/TON/M	kW HEAT/KTONM
MRCH 88	1606.00	5442.00	355.06	295.00	355.06	0.032	0.038	0.032	57.02	57.02	57.0	0.27	0.27	0.27	18962.00	0.29	11.06
APR 88	1333.00	5016.00	470.47	392.06	470.47	0.024	0.028	0.024	43.71	43.71	43.71	0.28	0.28	0.28	20684.00	0.29	11.02
MAY 88	1436.00	9450.00	506.02	422.35	506.02	0.035	0.042	0.035	44.10	44.10	44.10	0.28	0.28	0.28	21354.00	0.44	17.08
JUN 88	1530.00	8063.00	543.04	452.53	543.00	0.030	0.036	0.030	65.03	65.03	65.03	0.42	0.42	0.42	22789.00	0.30	14.05
JUL 88	1718.00	12745.00	606.35	505.29	606.35	0.039	0.047	0.039	53.99	53.99	53.99	0.34	0.34	0.34	25843.00	0.49	19.01
AUG 88	1190.00	8080.00	420.00	350.00	420.00	0.036	0.043	0.036	114.07	114.67	114.67	0.73	0.73	0.73	30649.00	0.26	10.16
SEPT 88	1530.00	7629.00	542.82	452.35	542.02	0.026	0.032	0.026	56.25	56.25	56.25	0.36	0.36	0.36	19256.00	0.40	15.27
OCT 88	1546.00	9811.00	545.65	454.71	545.65	0.037	0.044	0.037	52.84	52.84	52.84	0.47	0.47	0.47	12361.00	0.79	30.59
NOV 88	1612.40	11749.00	569.08	474.24	569.08	0.031	0.037	0.031	65.15	65.15	65.15	0.41	0.41	0.41	15053.00	0.78	30.68
DEC 88	1449.40	7467.00	511.55	426.29	511.55	0.027	0.033	0.027	86.79	86.79	86.79	0.41	0.41	0.41	13753.00	0.54	20.93
JAN 89	866.30	4530.00	305.65	254.71	305.65	0.028	0.033	0.028	92.32	92.32	92.32	0.43	0.43	0.43	6538.00	0.69	26.74
FEB 89	878.75	3931.00	310.13	258.44	310.13	0.027	0.032	0.027	55.27	55.27	55.27	0.50	0.50	0.50	5844.00	0.67	25.93
MRCH 89	926.00	6060.00	326.82	272.35	326.82	0.044	0.053	0.044	45.45	45.45	45.45	0.11	0.11	0.11	2181.00	2.78	107.10
APR 89	1129.00	6690.00	398.47	332.06	398.47	0.040	0.048	0.040	57.47	57.47	57.47	0.14	0.14	0.14	1772.00	3.78	145.53
MAY 89	1335.00	9850.00	471.18	[illegible]	471.18	0.050	0.060	0.050	53.66	53.66	53.66	0.13	0.13	0.13	3573.00	2.76	106.26
JUN 89	1185.00	9831.00	418.24	348.53	418.24	0.063	0.076	0.063	89.00	89.00	89.00	0.24	0.24	0.24	4550.00	2.16	83.28
JUL 89	356.00	1992.00	125.65	104.71	125.65	0.093	0.111	0.093	295.67	295.67	295.67	1.73	1.73	1.73	6000.00	0.33	12.80
AUG 89	333.00	2332.00	117.53	97.94	117.53	0.156	0.187	0.156	64.05	64.05	64.05	0.50	0.50	0.50	5400.00	0.43	16.65
SEPT 89	T 21376	132103	7545	6287	7545	1	1	1	1394	1394	1394	8	8	8	236562	18	704.14
OCT 89	A 1187.56	7343.50	419.14	349.28	419.14	0.05	0.05	0.05	77.45	77.45	77.45	0.43	0.43	0.43	13142.33	1.01	39.12
NOV 89																	
DEC 89																	
JAN 90																	
FEB 90																	

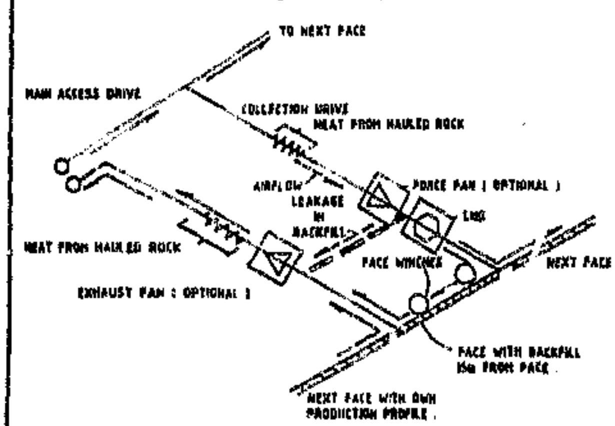
W.A.G.M. SOUTH DIVISION

PROJECT:

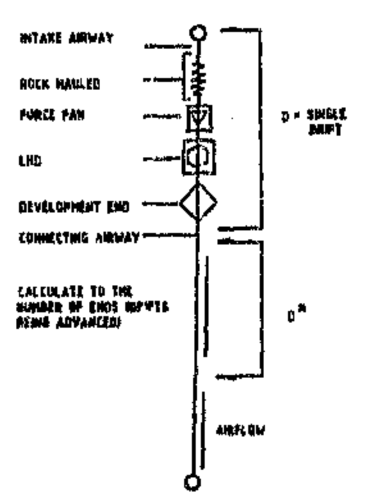
TITLE: Air and Heatflow Module - Phase 1 and 2



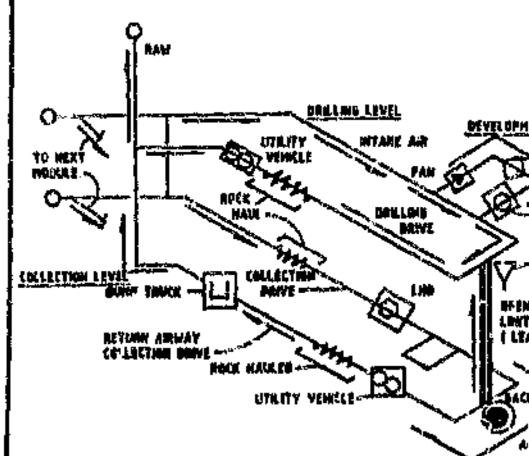
NARROW REEF TRACKLESS MINING (OVERSTOPING & VCR STOPING WEST OF SHORELINE) UP TO 1.5m Std. WIDTH TO NEXT FACE.



CUT & FILL OR 'EC' REEF UNDERSTOPING (1.5 TO 5.0m)



VERTICAL CRATER RETREAT MINING (15 - 150



Appendix H

Parameters to be measured on
"heat stress indices" for operators
Time

Physiological

1. Base-line heart rate (Hr) line
2. Operational heat rate press.
3. Body temp. rectal or drivers corrected for core by using oral temp.
4. Mean skin temp.
5. Age, height, weight and body area, mass index
6. VO2, RQ, SL are calculated
7. Percentage HR increase calculated*
8. Blood pressure

Influential factors

1. Type of clothing worn
2. Interview operators before and after

Environmental

Base line conditions:-

1. Temp bl = Temp, at base line ambient
2. Vap. press bl = Vapour @ base line
3. Velocity relative to (measured by means of kata) as check but premarily by velometer
4. Globe temperature (Radiant)
5. Temp. natural wet bulb

Cabin Parameters:-

1. Body or vehicle wall temp.
2. Engine inlet and outlet temp
3. Portion of engine relative to driver
4. Temp./ wet and dry in

Calculate :-

1. Sweat loss g/kg body weight

HEAT STRESS INDICES

Format of Field Trials

A. Input data measured

1. Physiological data : (Base line)
   - Subject name and ID no.
   - Heart rate, profile exposure, charateristics at base line information.
   - Bodymass, height and age.
   - Work category.
   - Heart rate vs work rate b/min vs watts.
   - Heart rate vs lung function in peak flow (l/min).
   - Estimated Vo2 max at l/min^{-1}.
     at ml/kg^{-1} min.
   - Mass index.
   - Temperature skin.
2. Influencial factors (Physiological)
   - Type of clothing used.
   - Condition of driver (opinion).
3. Cabin parameters or immediate influences
   - Body or wall temperatures of vehicle.
   - Temperatures : globe, natural wetbulb, drybulb.
   - Relative airspeed in cabin.
   - Position of engine in relation to driver.
4. External influences : (Ambient Conditions)
   - Temperature, globe, psychrometric wetbulb, drybulb.

- Airspeed.
- Temperature engine inlet and return.

5. Physiological_data : (operational)

- Heart rate over entire shift.
- Temperature skin.
- Sweat rate apparent.
- Well being of driver.

Remarks

- This study has been done on two very different projects.
- The first trial called 'Case 1 - Cool' was done where external ambient influences were negligable.
- Trial number called 'Case 2 - Hot' was carried out in adverse environmental condition (physiologically speaking) done on location
- The information gathered is now used to calculate the parameters necessary to assess the heat stress/strain discomfort and influences on the machine driver preventing him from functioning satifactorily.

B. Output data

Heat balance = M - W - Q - S = R + C + E + G = δS

1. Heat stress after Kamon [5-16]
   - Radiant heat transfer.
   - Convection heat.
   - Evaporation heat.
   - Influence of clothing.
   - Wetbulb globe temperature.
   - Sweat rate : Evaporation effectiveness (req/eff).
     maximum (req/max).
   - Psychrometric wetbulb temperature.
   - Strain analysis.
   - Heat stay limit vs WBGT.
   - Metabolic workrate (metabolic energy production). (M) minus mechanical work (W).

2. Cooling power concept after Stewart [5-29]
   via the calculation of :
   - Radiant heat transfer.
     temperature.
   - Convective heat transfer.
   - Latent heat transfer.
   - Sweating efficiency.
   - Evaporative heat transfer.
   - Sweat rate.
   - Metabolic work rate as per baseline.
   - Respiratory heat exchenge.
   - Water vapour pressure.
   - Metabolic workrate as per reference 5-28. and M = 343 Qr (20,39 - c)/100.

   also calculate CET, ET & Hb as comparator.

3. <u>Heat balance equation after NIOSH</u> [5-11]
   Change in body heat content by evaluating :
   - Convective heat exchange.
   - Radiant heat exchange.
   - Evaporative heat exchange.
   - Maximum water vapour uptake capacity.

4. <u>Heat stress based on WBGT - index after ISO</u> 7243(1982)
   this is necssary to look at maximum work rate vs time at work by :
   - Natural wetbulb temperature.
   - Globe temperature.
   - Drybulb temperature.
   - Estimating metabolic work rate.
   - WBGT mean
   - WBGT Twa.
   - Clothing influence.
   - Reference values of WBGT index vs
   - Metabolic work rate vs
   - Metabolic work rate class

5. <u>Microclimate cooling effect on operators</u>
   (initial study)

6. <u>Comparison of the various indexes</u>

Additional information on formulae used

1. Metabolic work rate (using baseline tests)
   (also see equation 6)

W3 = Wm^2 = (W1+((W2-W1)*((Hr3-Hr1)/(Hr2-Hr1)))*As

Where W3 = Required metabolic work rate
Hr1 & W1 = Condition 1 parameters
Hr2 & W2 = Condition 2 parameters
'As' is skin area = 0,217 $mt^{0,425}$ * $Ht^{0,725}$

2. Stepping height for baseline

   (W * 6000)/(9,81 * SR * M)

Where W is work load in Watts
SR is stepping rate (s/min)
M is body mass in kg

3. Qr = Vo2 = Ventilation rate or O_2 consumption
   = 0,52 + 0,0214 (Hr - 70) in l/min

4. Qr max = Vo2 max = 0,172 + 0,525 ffm in l/min

   Where ffm = fat free body mass

5. Qr max = Vo2 capacity = 0,52 + 0,0417 Bm

   Where Bm = Gross body mass

6. W at 145 b/min, assume straight line performance
   based on equa 1 = 100 + (((145-H2)/(H2-H1)*(W@H2-W@H1)

FORMULAE AFTER KAMON (1981:611)

1. R = Fcl.kr.(Tr^4 - Tsk^4) See 4
= RADIANT HEAT.exchange

Where:
- Fcl is insl.value cloths correction = (1 + 0,85*0,8 Iclo)
- kr is coeff Temp - Energy Stef Boltzm. const & emmisivity for black body
- Tr is mean radiant derived from Tg where:
  $Tr^4 = Tg^4 + kg\ V^{0,5}\ (tg - tdb)$
  Where: kg is coeff.heat transfer between globe and air
  Tg is abs.Temp of the globe
- tsk = 273 + 36 = 309°k

2. C = $Fcl*Kc*V^{0,5}(tdb - tsk)$ See 5

Where C = Convective Heat exchange
- Kc is convers factor Temp to Energy
- V is air movement
- tdb is dry bulb
- tsk mean skin Temp
- Fcl is $1(1 + 0,155*8,5*V^{0,6}*Iclo)$

3. Ereq = M ± R ± C
= Evap. Required

Where M is metabolic heat load $W.m^{-2}$

4. R = Fcl $4,36*10^{-8}$ [$(tr + 273)^4 - 9,117*10^{-9}$] $W.m^{-2}$

tt = $[\sqrt[4]{(tg + 273)^4 + 2,47*10^8*V^{0,5}(tg-tdb)}] - 273$ C

5. C = $Fcl.0,5*V^{0,6}(tdb - 36)\ W.m^{-2}$

6. Emax = $Fpcl*Ke*V^{0,5}$ (Psk - Pa) = Environ.Cap.for Evap.(See 10)
Ke is convers press. to energy.
Psk is vap.press skin @ $\bar{t}sk$ = 44 mm HG
Pa is ambient vap pres for tpwb & tdb (see 9)

W = HSI/100 = Ereq/Emax

Where HSI is heat stress index by Belding and Hatch
W = degree of wetedness due to sweating

7. ELS = Sweat rate of 1 $L.hr^{-2}$

8. E eff = $Sw*Zs*e^{-k*W} = 380*3,06*e^{-1,52W}$ in $W.m^{-2}$

Where E eff. is evap. sweat in terms of energy transfer
Sw is sweating rate limited to 1 $L.h^{-1}$
Zs is convers. fact from Sweat to energy
k is a regression constant

9. Pa = $(4,82e^{-0,0629*tpwb})$,00066*BP*(tdb -tpwb) [(1+0,00115)*
(tdb-tpwb)] in mm HG

Where: tpwb is psychro. wetbulb

10. ρcl for Emax = $1(1 + 0,143*8,5*V^{0,6}*Iclo)$

11. Conversion tpwb - tnwb

tpwb = tnwb - 0,5-0,13 (tg-tdb) for V > 1 $m.s^{-1}$ in °C
tpwb = tnwb - 1,5-0,13 (tg-tdb) for V < 1 $m.s^{-1}$ in °C

12. Time limit = 60 / (E req - E max)

HEAT STRESS INDEX FORMULAE

(After Stewart- 1984:495)

1. Cooling Power Concept:

(Where Dátwb to tdb < 2°C)

CP = f$_r$*hr (ts - tr) + hr (ts - ta) w*he (ps - pa)

Where: fr = view factor for radiant heat exchange from human

hr = radiant hea transfer coefficient w/m² °C

= 4,61 (1+(tr+ts)/546)^3-Stefan Boltzman radiant coefficient

ts = mean skin temperature measured or default @ 36,5°

tr = Radiant temperature of surroundings, °C

he = Experimentally determined convective heat transformation coeff.

= 0,608*P^{0,6}*V^{0,6}

ta = ambient dry-bulb temperature, °C

W = wet sk n fraction

he = evap, heat transfer coefficient

= 1587*hc*P/(P - pa)²

pa = water vapour pressure in ambient air, kPa.

= P'ws - AP (tdb - twb), kPa

Where P'ws = 0,6105.exp (17,27 twb/(237,3 + twb)), kPa

A = 0,00 6 4/°C

ps = saturated water vapour pressure at temp. ts, kPa

Notes

- Resiratory heat exchange neglected
- Conductive heat transfer neglected
- If 'ts' and 'w' is linked to a safe rectal temperature, then an equilibrium tr will be achieved in all cases where CP ≥ M
- M is metabolic energy generation also called metabolic heat/O² consumption
- This equation is incorrect for elevated radiant tempera- tu e and when the gap between twb and tdb > 2°C - therefore use the next equation

2. Cooling power concept or Equivalent Cooling power

(Where δtwb to tdb > 2°C)

CP = fr*hr (ts - tr) + hc (ts - ta) + λ *ηs*Sr + Q

Where: fr, hr and hc are as per equation 1

ηs = Efficency of sweat as cooling mech. for partial wet person and sweat dripping up to Emax

= E/λ*Sr where: E = As*w*he*(ps - pa) and w,he,ps & pa is as per equation 1

Where: E = Evaporative heat transfer

As = Skin surface area, m^2 = 0,217 $mt^{0,425}$*$Ht^{0,725}$

Where: mt = mass of human body, kg

Ht = height of person, m

λ = latent heat of vaporization of sweat, kJ/kg

= 2501 - 2,387 twb

Sr = Sweat rate, kg/m²s~TΣ and

TΣ = (0,1 ts+0,9tr) using TΣ read off Sweat rate from

Sr = Sweat rate, kg/m2 S and ~ TΣ

Where: T = Thermoregulatory signal °C

Sr = 36-37°C then Sr = (0,321/60) * TΣ -36

= 37,1-38°C then Sr = 0,321+(0,785/60) * TΣ -37,1

= 38,1-39°C then Sr = 1,106+(0,295/60) * TΣ -38,1

Emax = As*965 ($P^{1,6}$/(P - pa)²)*$V^{0,6}$ (ps - pa)

Where: P = Atmospheric pressure, kPa

and

Q = Resiratory heat exchange

= 1,7*10^6*M*cp (two - tw)

Where: M = Metabolic energy production = W*As

Cp = Specific heat of moist air = 6000 J/kg °C

two = 32,6 + 0,066 ta + 0,20 pa

Notes

- Applies to any condition found underground, especially in TM^3 projects where tr > tdb > twb
- Ratios of V02 max ~ M ~ heart rate is shown in equation 3

3. Metabolic Energy (M)

M = 343 Qr (20,39 - e)/100

Where: Qr = Respiratory flow rate (l/min)

e = % 02 in exhaled air

343 = constant

20,39 =% 02 in atmosphere by volume

(20,39 - e) = 02 consumption

and

Note: Muscles may be ~20% max when performing heavy physical work

Now

Prediction of V02 m. from parameters:
age, body mass, body height, relative fat, heart rates at various sub-max work loads and max Heart Rate

Use graphs F1, 6, 7 & F4 or ref 5.28 or the following formulae :

i. Qr = Vo2 in l/min = 0,52 + 0,0214 (hr - 70)

ii. Qr = Vo2 max in U/min = 0,172 + 0,525 FFM

Where:FMM = fat free body mass in kg

iii. Qr = Vo2 Capacity in l/min = 0,55 + 0,0417 BM

Where:BM = Cross body mass in kg

4. Radiant Temperature (using black globe)

$$Tr = [(Tg + 273)^4 + (1,1*10^8*V^{0,6}/0,95*D^{0,4})*(Tg - Ta)]^{0,25} - 273$$

Where:D = Ø globe (m)

Ta = Tdb

6. Heat balance equation

M = As fr hr (ts-tr)+As hc (ts-ta)+As*e*he (ps-pa)

Where: all factor are as previously mentioned and as per 'CP' equation. As is skin area

---

7. Cooling power values for safe heat exposure

$'CP\ 10^{-6}' = R + C + E\ max$

R = 4,93 As (ts-tr) = Radiant heat exchange

$C = As\ 0,608\ P^{0,6}\ V^{0,6}\ (ts-ta)$

$E\ max = As\ 965\ (P^{1,6} / (P-pa)^2)\ V^{0,6}\ (ps-pa)$

Where ts is taken for a 10^{-6} change of heat stroke i.e.

ts ≥ 40°C conditions

and

$$ts \text{ for } W/m^2\ 100 \text{ to } 240 = \left[35,8 - \frac{(35,8-34,6)*(240-M)}{240}\right]$$

$$= 35,8 - (0,005\ (240-M)$$

$$ts \text{ for } W/m^2\ 240 \text{ to } 300 = \left[34,6\quad \frac{(34,6 - 33,2)*(300-M)}{300}\right]$$

$$= 34,6 - (0,0047\ (300-M)$$

8. Thermal comfort (as TC) for unacclimatised people

in TC, ts = 35,7 - 0,032 (M-W) / As = Skin temperature

and E = 0,42 ((M-W)-58) = Evapotative cooling (Sweat rate)

9. Relative Humidity

o = (Pa/P"ws)*100%

and Pa = P'ws-AP(tdb-twb)

P'ws = Saturated vapour press @ twb kPa

= 0,6105 exp (17,27 twb / (237,3 twb) kPa

A = 0,000644°C

= Bar pressure in kPa

$$P''ws = 0,6105 \exp (17,27\ tdb / (237,3 + tdb))\ kPa$$

Remarks

Equa 8 and 9 are used to check on comfort level for unacclimatised operators with the view of determining if these drivers need to be acclimatised

Heat balance equation (USD of H & H Services 1986)
(NIOSH 86 - 113) (5 - 7)

Where ΔS = Change in body heat content
M-W = Total metabolism - external work performed
C = Convec heat exchange
R = Radiant
E = Evaporative

1. C = hc(ta-tsk) = Corrective heat exchange

Where: hc = 2,38 $(\bar{t}sk-ta)^{0,25}$ at very low airspeeds
= 3,5 + 5,2 Var where Var is relative airspeed < 1m/s
= 8,7 $Var^{0,6}$ Where Var is > $1m.s^{-1}$

and Var = Va+0,0052 (M-58) if movement is due to muscular activity

or

Simply add $0,7ms^{-1}$ if muscular only

plus

Sensible heat exchange due to clothes (Fcl)
and Fcl = 1/(1 = (hc + hr) Iclo

Where Icl is the thermal insulation for clothes

also

C = hc Fcl (ta-36) in WM^{-2}

and

Iclo = (0,8(0,06 + 0,09 + 0,26 + 0,04 + 0,08) +
(pants, Tshirt = underwear; Trousers; Socks; Boots)

2. R = hr Fcl $(Tr-Tsk)^4$ = Radiant heat exchange in $W/m^2/c$

Where hr is coefficient of radiant heat exchange
= 4 Esk * (Ar/Ado) $\left[(tr=tsk) / 2 + 273\right]^3$
= $5,67 * 10^{-8}$ $W/m^2/{}^\circ k^4$

and Ar/Ado is the effect of body position on emissivity
Where Ar is area exposed to radiation

Adv = Du Bois' formulae in m^2

= 0,00718 * Weight 0,425 / Height 0,725

and W is in <u>kg</u> and H in <u>cm</u>

and Ar/Adv = 0,77 Standing

= 0.70 Seated

= 0,67 Crouched

tr = tg + 1,8 Va ^{0,5} (tg-ta)

tsk = 36°C

3. <u>E max =(psk,s - Pa) / Re = Evaporative heat exchange</u>

Where Emax <u>is</u> max water vapour uptake capacity W/m^2

psk <u>is</u> Sat H_2O vapour press at 36°C ts = 5,9 kPa

pa <u>is</u> partial H_2O vapour press at ta in kPa

Re <u>is</u> evaporation resistance of air and clothes

= 1 / (16,7) / (hc) / Fpcl

Where Fpcl <u>is</u> reduction factor for loss in latent heat exchange due to clo

= 1 / (1 + 0,92 hc) / Icl

Sweat rate default = 650 gms/hour for 8 hours acclimatised

= 400 gms/hour for 8 hours unacclimatised person

S req = E req

Where S req <u>is</u> Required sweat (W/m^2) also in $gms/hr/m^2$

W/m^2 = ($gms/hr/m^2$) * 0,63

W = E req/E max is wettedness factor

E req <u>is</u> Required evaporation = M + C + R

Evap Eff <u>is</u> of nude person = 1 - 0,5/e $^{-6,6(1-W)}$

e is base of natural logorithm

::FILE NAME:1470HSTE

APPENDIX I

LOCALITY :83 TN3

BAR PRESS: 106 kPa

DATE : 07/12/90

HEAT STRESS ANALYSIS OF DIESEL POWERED VEHICLE OPERATORS

INPUT PARAMETERS

::PERSON : NAME: LUCKY ID NUMBER : 1421670 TYPE OF MACHINE : LHD *

::PHYSIC : AGE: 32 BODY MASS: 60.8 HEIGHT : 1.7 SKIN AREA : 1.83 M2

::HEART PROFILE : HR

:: 54 W 96 b/min MET CURVE :(54+(46*((HR100-HR)/(HR100-HR54))))/As

:: 70 W 104 b/min M @ HEART RATE 145 b/min.= 147.92

:: 100 W 120 b/min M @ HEART RATE 70 b/min.= 4.17

::BASELINE INFORMATION CABIN PARAMETERS :EXTERN. INFLUENCE - AMBIENT CONDITIONS

TIME	HEARTRATE	WALL TEMP	Tg	Tmwb	Tdb	Airspeed	Tg	Tpwb	Tdb	Airspeed
HR:MIN	b/min	celsius	celsius	celsius	celsius	m/s	celsius	celsius	celsius	m/s
07:39 STR	80	30.40	29.15	29.4	24.85	0.29	28.35	24.85	28.65	0.19
2	80	30.40	29.15	29.4	24.85	0.29	28.5	25.1	28.8	0.19
4	80	30.40	29.15	29.4	24.85	0.29	28.85	25.7	29.1	0.31
6	77	30.88	29.95	31.9	26	1.02	28.9	25.5	29.2	0.28
8	77	30.56	31.15	33.05	27.15	0.22	29	25.65	29.5	0.23
10	77	31.52	31.7	30.15	25.85	0.20	28.95	25.65	29.6	0.37
12	77	31.68	31.8	30.9	26.45	0.27	29	24.95	28.6	0.25
14	77	31.52	31.8	28.95	25.4	0.20	29.05	24.7	28.15	0.29
16	81	31.52	31.6	28.8	25.35	0.19	29.05	24.7	28	0.30
18	81	31.20	31.45	29.55	25.55	0.21	29.1	24.9	28.05	0.27
20	81	31.20	31.85	31.35	25.25	0.19	29.1	24.9	28	0.28
22	81	29.44	31.85	29.75	24.95	0.19	29.15	24.75	27.95	0.28
24	81	29.12	31.45	28.95	24.5	0.20	29.15	24.75	27.95	0.21
26	74	30.56	31.45	32.6	26.4	0.34	29.15	24.65	28.05	0.22
28	74	29.44	32.2	33.15	27.35	0.23	29.15	24.65	28	0.20
30	74	30.08	33.25	34.25	29.15	0.26	29.25	25.25	28.2	0.23
32	74	32.80	34.2	35.15	29.6	0.19	29.3	25.4	28.25	0.23
34	74	34.08	34.75	33.95	28.55	0.22	29.5	26.75	30.2	0.19
36	80	35.36	35.2	34.45	29.3	0.20	29.9	26.6	30.25	0.19
38	80	34.72	35.75	33.95	29.5	0.19	30.2	26.8	30.5	0.22
40	80	35.68	36.15	33.55	29.4	0.20	30.4	26.8	30.65	0.23
42	80	36.64	36.35	33.45	29.25	0.19	30.55	26.8	31.25	0.24
44	80	37.12	36.45	33.5	29.25	0.19	30.8	26.95	31.55	0.20
46	84	37.44	36.45	34.9	30.05	0.66	30.95	25.95	30.15	0.20
48	84	37.44	37.55	37.35	30.1	0.46	31	26.3	30.95	0.19
50	84	38.08	38	34.55	28.65	0.29	30.85	25.2	30.05	0.26
52	84	39.20	38.3	36.5	29.8	0.22	30.65	24.85	29.15	0.19
54	84	38.24	38.4	34.2	28.95	0.27	30.4	24.85	29	0.20
56	74	38.88	38.2	34.75	28.9	0.19	30.1	24.9	28.95	0.19
58	74	38.56	37.8	33.45	28.5	0.19	29.85	24.85	28.9	0.20
60	74	38.08	37.35	33.15	28.4	0.26	29.8	24.75	28.85	0.19
62	74	37.92	37.05	32.95	28.35	0.19	29.75	24.8	28.8	0.19
64	74	37.92	36.8	33.4	28.75	0.19	29.65	24.65	28.6	0.20
66	72	37.76	36.6	33.25	28.85	0.19	29.65	24.85	28.75	0.23
68	72	37.92	36.55	33.65	28.9	0.19	29.65	24.9	28.9	0.19
70	72	38.56	36.5	33.3	28.8	0.19	29.65	24.85	28.8	0.22
72	72	38.56	36.55	33.7	28.95	0.21	29.6	24.65	28.6	0.23
74	72	38.56	36.6	33.8	29.2	0.19	29.65	24.9	28.75	0.19
76	70	38.56	36.7	33.35	28.85	0.19	29.75	25.1	29.35	0.21
78	70	38.72	36.65	33	28.5	0.19	30.15	26.25	30.95	0.19
80	70	38.40	36.55	32.95	28.5	0.20	30.5	26.2	30.65	0.20
82	70	38.08	36.45	33.15	28.65	0.20	30.5	26.4	30.75	0.31

::FILE NAME:1470HSTE APPENDIX I

:: HEAT STRESS ANALYSIS OF DIESEL POWERED VEHICLE OPERATORS

LOCALITY :83 TM3

BAR PRESS: 106 kPa

INPUT PARAMETERS

DATE : 07/12/90

::PERSON : NAME: LUCKY ID NUMBER : 1421670 TYPE OF MACHINE : LHD *

::PHYSIC : AGE: 32 BODY MASS: 60.8 HEIGHT : 1.7 SKIN AREA : 1.83 M2

::HEART PROFILE : HR

:: 54 W 96 b/min MET CURVE :(54+(46*((HR100-HR)/(HR100-HR54))))/As

:: 70 W 104 b/min M @ He ?T RATE 145 b/min.= 147.92

:: 100 W 120 b/min M @ HEART RATE 70 b/min.= 4.17

::BASELINE INFORMATION CABIN PARAMETERS :EXTERN. INFLUENCE - AMBIENT CONDITIONS

TIME	HEARTRATE	WALL TEMP	Tg	Tnwb	Tdb	Airspeed	Tg	Tpwb	Tdb	Airspeed
HR:MIN	b/min	celsius	celsius	celsius	celsius	m/s	celsius	celsius	celsius	m/s
84	70	37.76	36.45	33	28.5	0.19	30.45	26.3	30.8	0.19
86	69	37.76	36.35	33.25	28.7	0.19	30.55	26.4	31.05	0.19
88	69	37.76	36.35	33.05	28.5	0.19	30.65	26.4	31	0.21
90	69	37.92	36.4	33.15	28.55	0.19	30.8	26.25	30.8	0.19
92	69	37.76	36.45	33.05	28.5	0.23	30.85	25.5	30.7	0.68
94	69	37.76	36.45	33.2	28.65	0.19	30.75	25.95	31.4	0.29
96	72	37.76	36.45	33.15	28.6	0.19	30.8	25.1	29.8	0.27
98	72	37.92	36.5	33.3	28.65	0.19	31.25	28.8	33	0.23
100	72	37.92	36.55	33.2	28.55	0.19	32.1	28.4	31	0.19
102	72	37.92	36.55	33.2	28.6	0.19	32.35	28.25	30.65	0.19
104	72	37.76	36.45	33.8	29.1	0.20	32.35	28.6	30.95	0.40
103	81	37.44	37.1	35.75	30.5	0.19	33.05	28.45	33.05	0.76
108	81	38.08	37.85	37.4	31.55	0.46	33.5	26.15	33	0.19
110	81	38.72	38.35	37.6	33.25	0.33	33.5	28.2	34.7	0.50
112	81	38.08	33.9	37.35	32.85	0.24	34.4	28.4	33.5	0.27
114	81	38.24	39.1	35.15	32.25	0.37	34.85	28.6	34.9	0.19
116	90	39.68	38.85	36.15	32.5	0.25	35.3	28.25	34.6	0.27
118	90	40.00	38.9	37.6	32.6	0.50	35.4	28.55	33.25	0.19
120	90	40.00	38.8	35.75	31.45	0.19	35.15	28.7	33.2	0.19
122	90	39.84	38.7	36.1	31.7	0.19	34.9	28.7	33.2	0.19
124	90	39.52	38.7	35.6	31.3	0.19	34.75	28.1	33.25	0.32
126	83	39.20	38.6	35.55	31	0.19	34.9	28.1	32.8	0.24
128	83	39.04	38.55	35.65	31.05	0.21	35.7	28.75	36.1	0.87
130	83	39.04	38.55	35.55	31	0.19	37.1	29.1	35.25	0.24
132	83	39.20	38.55	35.9	30.75	0.19	37.6	29.15	36.7	0.27
134	83	39.52	38.7	35.5	30.65	0.20	37.55	28.85	36	0.25
136	89	39.52	38.8	35.5	30.6	0.19	37	28.55	35.25	0.27
138	89	39.68	38.8	35.5	30.55	0.19	36.15	28.3	33.65	0.19
140	89	39.84	38.9	35.75	30.65	0.19	35.2	28.15	33.3	0.19
142	89	39.84	38.9	35.55	30.75	0.19	34.6	28.5	33.65	0.22
144	89	39.68	38.85	35.8	30.85	0.21	34.55	28.95	35.6	0.22
146	86	39.20	38.75	35.8	30.75	0.19	34.9	28.4	33.6	0.19
148	86	39.20	38.8	35.55	30.65	0.19	35.1	28.95	35.7	0.46
150	86	39.20	38.8	35.55	30.6	0.23	35.45	29.1	36.55	0.37
152	86	39.52	38.8	35.6	30.6	0.19	37.2	30.8	39.1	0.59
154	86	39.20	38.75	35.95	30.6	0.21	38.15	30.45	36.05	0.27
156	104	39.04	38.75	35.55	30.95	0.20	38.1	30.3	35.55	0.32
158	104	39.04	38.7	35.85	30.45	0.24	37.75	30.35	36.6	0.19
160	104	39.04	38.8	35.7	30.55	0.22	37.5	29.95	36.3	0.32
162	104	39.04	38.8	35.6	30.45	0.19	37.45	30.1	38.55	0.24

::FILE NAME:1470HSTE — APPENDIX I

HEAT STRESS ANALYSIS OF DIESEL POWERED VEHICLE OPERATORS

LOCALITY :83 TM3

BAR PRESS: 106 kPa

INPUT PARAMETERS

DATE : 07/12/90

::PERSON : NAME: LUCKY ID NUMBER : 1421670 TYPE OF MACHINE : LHD *

::PHYSIC : AGE: 32 BODY MASS: 60.8 HEIGHT : 1.7 SKIN AREA : 1.83 M2

::HEART PROFILE : HR

54 W	96 b/min	MET CURVE :(54+(46*((HR100-HR)/(HR100-HR54))))/As	
70 W	104 b/min	M @ HEART RATE 145 b/min.=	147.92
100 W	120 b/min	M @ HEART RATE 70 b/min.=	4.17

BASELINE INFORMATION		CABIN PARAMETERS					EXTERN. INFLUENCE - AMBIENT CONDITIONS			
TIME	HEARTRATE	WALL TEMP	Tg	Tnwb	Tdb	Airspeed	Tg	Tpwb	Tdb	Airspeed
HR:MIN	b/min	celsius	celsius	celsius	celsius	m/s	celsius	celsius	celsius	m/s
164	104	39.20	38.75	35.6	30.4	0.21	38.8	30.55	41.15	0.38
166	123	39.52	38.75	35.6	30.4	0.19	39.35	28.75	36.6	0.32
168	123	39.52	38.7	35.55	30.55	0.19	39.1	27.9	35.7	0.50
170	123	39.52	38.6	35.7	30.5	0.25	38.26	28.25	35.95	0.24
172	123	39.52	38.55	35.8	30.4	0.24	37.45	29.1	36.7	0.24
174	123	39.20	38.6	35.8	30.6	0.21	37.25	28	35.1	0.33
176	115	39.20	38.6	35.75	30.35	0.19	36.35	27.75	34.5	0.43
178	115	39.20	38.6	35.7	30.3	0.19	35.85	28.55	35.85	0.40
180	115	39.20	38.6	34.4	30.45	0.19	35.75	28.6	34.9	0.19
182	115	39.20	38.6	34.5	30.35	0.19	35.75	29.1	36.25	0.31
184	115	39.20	38.6	34.45	30.46	0.19	36.1	30.9	36.25	0.19
186	129	39.04	38.6	35	30.2	0.22	36.25	30.95	36.05	0.24
188	129	39.20	38.6	35.55	30.35	0.19	36.3	30.85	35.8	0.23
190	129	39.20	38.55	35.6	30.15	0.19	36.25	30.85	35.65	0.19
192	129	39.20	38.55	35.8	30.15	0.25	36.3	31.5	36.65	0.20
194	129	39.04	38.45	36.15	30.35	0.20	36.45	30.65	35.05	0.21
196	123	39.04	38.45	36.15	30.3	0.23	36.55	30.45	34.6	0.20
198	123	38.88	38.45	36.2	30.1	0.19	36.55	[illegible]	34.35	0.19
200	123	38.88	38.45	36.3	30.1	0.19	36.45	30.3	34.25	0.20
202	123	38.88	38.45	36.2	30.25	0.19	36.45	30.3	34.2	0.20
204	123	39.04	38.45	36.15	30.35	0.21	36.35	30.35	34.25	0.23
206	132	38.88	38.35	36.2	30.2	0.20	36.35	30.3	34.15	0.19
208	132	38.88	38.35	36.3	30.15	0.21	36.3	30.3	34.15	0.21
210	132	38.72	38.35	36.3	30.2	0.23	36.3	30.3	34.15	0.21
212	132	38.88	38.35	36.85	30.15	0.19	36.3	30.25	34.05	0.21
214	132	38.88	38.35	36.7	30.25	0.19	36.25	30.3	34.1	0.19
216	119	38.88	38.55	38.85	30.75	0.64	36.25	30.25	34.05	0.19
218	119	39.20	38.6	38.3	30.35	0.33	36.3	30.65	35.3	0.19
220	119	38.72	38.7	38.8	30.65	0.28	36.5	30.45	34.8	0.19
222	119	39.04	39.15	40.6	31.05	0.22	36.5	30.35	34.45	0.19
224	119	0.00	40	41.2	31.25	0.33	36.45	30.3	34.3	0.19
226	124	0.06	40.3	40.2	30.55	0.57	36.45	30.25	34.2	0.20
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00
AVG	92.10	36.74	36.95	34.65	29.47	0.24	33.33	27.69	32.53	0.26
MIN	69.00	0.00	29.15	28.80	24.50	0.19	28.35	24.65	27.95	0.19
MAX	132.00	40.00	40.30	41.20	33.25	1.02	39.35	31.50	41.15	0.87
STD	20.79	5.74	2.60	2.33	1.82	0.11	3.32	2.16	3.06	0.11
VAR	432.02	32.92	6.77	5.42	3.32	0.01	10.99	4.64	9.37	0.01

BASIC INPUT DATA , METABOLIC WORK RATE AND PSYCHROMTERIC DATA

METABOLIC HEAT PRODUCTION					PSYCHROMETRIC DATA				METABOLIC HEAT
HEARTRATE	OXYGEN CONSUMPTION Qr	Qr	OBSERVA TIME as per input	WORK RATE W	VAP PRESS 'Pa'	VAP PRESS 'Pa'	REL HUM RH	TEMP RAD Tr	M
b/m	VO2 BM	VO2 HR		W/m2	kPa	mmHG	%	C	W/M2
80	3.06	2.66	07:39 STR	42.63	2.98	1.02	73.37	28.03	157.20
80	3.06	2.66	2	42.63	2.93	0.96	74.10	28.18	157.20
80	3.06	2.66	4	42.63	3.07	0.78	76.20	28.59	157.20
77	3.06	2.02	6	32.12	3.01	0.93	74.30	28.23	151.31
77	3.06	2.02	8	32.12	3.03	1.00	73.48	28.56	151.31
77	3.06	2.02	10	32.12	3.02	1.05	72.90	[illegible]	151.31
77	3.06	2.02	12	32.12	2.91	0.94	74.32	29.40	151.31
77	3.06	2.02	14	32.12	2.87	0.85	75.42	29.80	151.31
81	3.06	2.87	16	46.13	2.88	0.78	76.36	29.89	159.17
81	3.06	2.87	18	46.13	2.93	0.70	77.39	30.00	159.17
81	3.06	2.87	20	46.13	2.94	0.68	77.71	29.97	159.17
81	3.06	2.87	22	46.13	2.90	0.73	77.01	30.10	159.17
81	3.06	2.87	24	46.13	2.90	0.73	77.01	30.13	159.17
74	3.06	1.38	26	21.62	2.87	0.83	75.71	30.41	145.41
74	3.06	1.38	28	21.62	2.87	0.80	76.02	30.19	145.41
74	3.06	1.38	30	21.62	3.01	0.60	78.81	30.26	145.41
74	3.06	1.38	32	21.62	3.05	0.55	79.51	30.14	145.41
74	3.06	1.38	34	21.62	3.28	0.75	76.37	28.89	145.41
80	3.06	2.66	36	42.63	3.23	0.84	75.12	29.61	157.20
80	3.06	2.66	38	42.63	3.27	0.86	74.92	29.96	157.20
80	3.06	2.66	40	42.63	3.26	0.93	74.04	30.19	157.20
80	3.06	2.66	42	42.63	3.22	1.24	70.66	29.99	157.20
80	3.06	2.66	44	42.63	3.24	1.31	69.92	30.21	157.20
84	3.06	3.52	46	56.63	3.06	1.16	71.61	32.28	165.06
84	3.06	3.52	48	56.63	3.10	1.40	69.29	31.07	165.06
84	3.06	3.52	50	56.63	2.87	1.63	67.55	31.67	165.06
84	3.06	3.52	52	56.63	2.84	1.31	70.43	31.95	165.06
84	3.06	3.52	54	56.63	2.85	1.22	71.30	31.78	165.06
74	3.06	1.38	56	21.62	2.87	1.16	71.91	31.00	145.41
74	3.06	1.38	58	21.62	2.86	1.16	71.89	30.62	145.41
74	3.06	1.38	60	21.62	2.84	1.20	71.54	30.71	145.41
74	3.06	1.38	62	21.62	2.86	1.14	72.15	30.50	145.41
74	3.06	1.38	64	21.62	2.83	1.12	72.37	30.49	145.41
72	3.06	0.95	66	14.61	2.87	1.08	72.77	30.36	141.48
72	3.06	0.95	68	14.61	2.87	1.13	72.21	30.24	141.48
72	3.06	0.95	70	14.61	2.87	1.10	72.48	30.32	141.48
72	3.06	0.95	72	14.61	2.83	1.12	72.37	30.44	141.48
72	3.06	0.95	74	14.61	2.88	1.05	73.10	30.36	141.48
70	3.06	0.52	76	7.61	2.90	1.26	70.86	30.07	137.55
70	3.06	0.52	78	7.61	3.09	1.43	68.99	29.52	137.55
70	3.06	0.52	80	7.61	3.10	1.29	70.34	30.38	137.55
70	3.06	0.52	82	7.61	3.14	1.21	71.00	30.30	137.55
70	3.06	0.52	84	7.61	3.11	1.31	70.11	30.17	137.55
69	3.06	0.31	86	4.11	3.12	1.39	69.34	30.15	135.59
69	3.06	0.31	88	4.11	3.13	1.36	69.62	30.37	135.59
69	3.06	0.31	90	4.11	3.10	1.34	69.81	30.80	135.59
69	3.06	0.31	92	4.11	2.91	1.84	65.85	30.93	135.59
69	3.06	0.31	94	4.11	2.98	1.96	[illegible]	30.24	135.59
72	3.06	0.95	96	14.61	2.86	1.54	[illegible]	[illegible]	141.48
72	3.06	0.95	98	14.61	3.67	0.97	73.02	29.85	141.48
72	3.06	0.95	100	14.61	3.69	0.38	82.16	32.95	141.48
72	3.06	0.95	102	14.61	3.67	0.33	83.37	33.66	141.48

BASIC INPUT DATA , METABOLIC WORK RATE AND PSYCHROMTERIC DATA

METABOLIC HEAT PRODUCTION : PSYCHROMETRIC DATA

HEARTRATE b/m	OXYGEN CONSUMPTION Qr VO2 BM	OXYGEN CONSUMPTION Qr VO2 HR	OBSERVA TIME as per input	WORK RATE W W/m2	VAP PRESS 'Pa' kPa	VAP PRESS 'Pa' mmHG	REL HUM RH %	TEMP RAD Tr C	METABOLIC HEAT M W/M2
72	3.06	0.95	104	14.61	3.75	0.31	83.79	33.47	141.48
81	3.06	2.87	106	46.13	3.56	1.19	70.69	33.05	159.17
81	3.06	2.87	108	46.13	2.92	3.06	58.12	34.15	159.17
81	3.06	2.87	110	46.13	3.38	2.42	61.12	32.20	159.17
81	3.06	2.87	112	46.13	3.52	1.47	68.06	35.19	159.17
81	3.06	2.87	114	46.13	3.48	2.22	62.30	34.79	159.17
90	3.06	4.80	116	77.64	3.40	2.30	61.85	35.93	176.85
90	3.06	4.80	118	77.64	3.58	1.24	70.21	38.29	176.85
90	3.06	4.80	120	77.64	3.63	1.12	71.35	36.61	176.85
90	3.06	4.80	122	77.64	3.63	1.12	71.35	36.19	176.85
90	3.06	4.80	124	77.64	3.45	1.53	67.64	35.89	176.85
83	3.06	3.30	126	53.13	3.48	1.27	69.98	36.48	163.10
83	3.06	3.30	128	53.13	3.44	2.99	57.69	35.38	163.10
83	3.06	3.30	130	53.13	3.61	2.05	63.30	38.47	163.10
83	3.06	3.30	132	53.13	3.52	3.08	57.10	38.27	163.10
83	3.06	3.30	134	53.13	3.48	2.81	58.62	38.72	163.10
89	3.06	4.59	136	74.14	3.44	2.52	60.43	38.28	174.89
89	3.06	4.59	138	74.14	3.48	1.63	66.73	38.00	174.89
89	3.06	4.59	140	74.14	3.46	1.52	67.66	36.63	174.89
89	3.06	4.59	142	74.14	3.54	1.49	67.86	35.32	174.89
89	3.06	4.59	144	74.14	3.54	2.42	60.91	33.69	174.89
86	3.06	3.94	146	63.63	3.51	1.53	67.55	35.88	168.99
86	3.06	3.94	148	63.63	3.53	2.49	60.46	34.64	168.99
86	3.06	3.94	150	63.63	3.52	3.00	57.49	34.52	168.99
86	3.06	3.94	152	63.63	3.87	3.35	55.13	35.77	168.99
86	3.06	3.94	154	63.63	3.87	1.56	66.66	39.79	168.99
104	3.06	7.80	156	126.66	3.96	1.38	68.29	40.01	204.36
104	3.06	7.30	158	126.66	3.97	1.38	68.32	39.59	204.36
104	3.06	7.80	160	126.66	3.80	2.07	62.87	38.47	204.36
104	3.06	7.80	162	125.56	3.69	3.63	54.08	36.64	204.36
104	3.06	7.80	164	126.66	3.65	5.55	46.62	36.97	204.36
123	3.06	11.86	166	193.19	3.41	3.41	55.58	41.35	241.70
123	3.06	11.95	168	193.19	3.22	3.55	55.19	41.54	241.70
123	3.06	11.86	170	193.19	3.31	3.39	55.86	40.24	241.70
123	3.06	11.86	172	193.19	3.51	3.13	56.86	38.09	241.70
123	3.06	11.86	174	193.19	3.29	2.92	58.28	38.92	241.70
115	3.06	10.15	176	165.17	3.26	2.69	59.68	37.72	225.98
115	3.06	10.15	178	165.17	3.40	2.99	57.77	35.85	225.98
115	3.06	10.15	180	165.17	3.48	2.22	62.30	36.38	225.98
115	3.06	10.15	182	165.17	3.54	2.77	58.78	35.37	225.98
115	3.06	10.15	184	165.17	4.10	1.38	68.10	35.99	225.98
129	3.06	13.15	186	214.19	4.13	1.25	69.35	36.41	253.49
129	3.06	13.15	188	214.19	4.11	1.19	70.05	36.67	253.49
129	3.06	13.15	190	214.19	4.12	1.12	70.81	36.70	253.49
129	3.06	13.15	192	214.19	4.27	1.23	69.37	35.99	253.40
129	3.06	13.15	194	214.19	4.10	0.95	72.78	37.53	253.49
123	3.06	11.86	196	193.19	4.07	0.86	74.01	38.19	241.70
123	3.06	11.86	198	193.19	4.05	0.80	74.78	38.18	241.70
123	3.06	11.86	200	193.19	4.04	0.78	75.03	38.09	241.70
123	3.06	11.86	202	193.19	4.05	0.76	75.30	38.11	241.70

BASIC INPUT DATA , METABOLIC WORK RATE AND PSYCHROMTERIC DATA

METABOLIC HEAT PRODUCTION : PSYCHROMETRIC DATA

	HEARTRATE	OXYGEN CONSUMPTION		OBSERVA	WORK RATE	VAP PRESS	VAP PRESS	REL HUM	TEMP RAD	METABOLIC HEAT
		Qr	Qr	TIME as	W	'Pa'	'Pa'	RH	Tr	M
	b/m	VO2 BM	VO2 HR	per input	W/m2	kPa	mmHG	%	C	W/M2
**	123	3.06	11.86	204	193.19	4.06	0.76	75.32	38.00	241.70
**	132	3.06	13.79	206	224.70	4.05	0.74	75.57	38.03	259.38
**	132	3.06	13.79	208	224.70	4.05	0.74	75.57	37.99	259.38
**	132	3.06	13.79	210	224.70	4.05	0.74	75.57	38.11	259.3[illegible]
**	132	3.06	13.79	212	224.70	4.04	0.73	75.83	37.96	259.38
**	132	[illegible].06	13.79	214	224.70	4.06	0.72	75.85	37.87	259.38
**	119	3.06	11.01	216	179.18	4.04	0.73	75.83	39.63	233.84
**	119	3.06	11.01	218	179.18	4.08	1.06	71.48	37.35	233.84
**	119	3.06	11.01	220	179.18	4.05	0.94	72.95	38.11	233.84
**	119	3.06	11.01	22[illegible]	179.18	4.05	0.84	74.24	38.17	233.84
**	119	3.06	11.01	22[illegible]	179.18	4.04	0.80	74.76	38.68	233.84
**	124	3.06	12.08	226	196.69	4.03	0.79	75.01	39.66	243.66
--	COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00
--	AVG	3.06	5.25	113.00	84.98	3.41	1.47	69.50	34.02	180.97
--	MIN	3.06	0.31	0.00	4.11	2.83	0.31	46.62	28.03	135.59
--	MAX	3.06	13.79	226.00	224.70	4.27	5.55	83.79	41.54	259.38
--	STD	0.00	4.45	65.62	72.78	0.44	0.88	6.97	3.79	40.84
--	VAR	0.00	19.78	4331.67	5296.42	0.19	0.78	48.56	14.35	1668.11

FILE NAME: STEWART SUMMARY

HEAT STRESS ANALYSIS OF DIESEL POWERED VEHICLE OPERATORS

INPUT PARAMETERS

APPENDIX J
LOCALITY : 83 TM3
BAR PRESS: 106 kPa
DATE : DECEMBER 19[illegible]0

TIME	HEARTRATE	TEMP SKIN	Tg	TEMP SKIN	Tdb	T JACKET	Tg	Tpwb	Tdb	Airspeed	
HR:MIN	b/min	celsius	celsius	celsius	celsius	celsius	celsius	celsius	celsius	m/s	
COUNT	114.00	1.00	1.00	1.00	1.00	1.00	114.00	114.00	114.00	114.00	1419HSTE LHD
AVG	108.95	76.00	40.00	34.00	38.00	0.40	42.40	31.32	39.00	0.89	
MIN	98.00	76.00	40.00	34.00	38.00	0.40	34.95	25.70	32.70	0.19	
MAX	125.00	76.00	40.00	34.00	38.00	0.40	49.00	33.85	44.35	4.31	
STD	5.16	0.00	0.00	0.00	0.00	0.00	3.03	1.72	2.43	0.72	
VAR	26.57	0.00	0.00	0.00	0.00	0.00	9.18	2.97	5.91	0.52	
COUNT	114.00	1.00	1.00	1.00	1.00	1.00	114.00	114.00	114.00	114.00	1419HSST LHD
AVG	86.29	76.00	40.00	34.00	38.00	0.40	36.62	29.01	35.95	0.67	
MIN	77.00	76.00	40.00	34.00	38.00	0.40	31.15	25.10	29.76	0.19	
MAX	101.00	76.00	40.00	34.00	38.00	0.40	42.70	31.55	39.60	2.27	
STD	6.30	0.00	0.00	0.00	0.00	0.00	2.47	1.64	2.19	0.53	
VAR	39.75	0.00	0.00	0.00	0.00	0.00	6.11	2.69	4.79	[illegible]	
COUNT	114.00	114.00	114.00	1.00	1.00	1.00	114.00	114.00	114.00	114.00	1636HSTE LHD
AVG	78.79	45.50	31.62	34.00	43.00	0.40	32.47	28.04	31.73	0.69	
MIN	67.00	29.70	27.95	34.00	43.00	0.40	27.80	24.00	27.20	0.19	
MAX	[illegible]	56.10	36.45	34.00	43.00	0.40	38.10	31.85	36.70	4.84	
STD	[illegible].03	5.98	2.18	0.00	0.00	0.00	2.82	1.99	2.29	0.77	
VAR	16.22	35.79	4.73	0.00	0.00	0.00	7.96	3.95	5.27	0.59	
COUNT	114.00	114.00	114.00	114.00	1.00	1.00	114.00	114.00	114.00	114.00	1413HSTE LHD
AVG	105.66	26.33	37.74	26.11	38.00	0.40	37.77	31.02	37.48	1.23	
MIN	95.00	0.00	32.70	0.00	38.00	0.40	33.20	26.50	28.90	0.21	
MAX	114.00	36.70	41.70	36.80	38.00	0.40	42.30	34.60	50.20	26.42	
STD	4.20	14.78	1.87	14.58	0.00	0.00	2.31	1.42	3.59	2.54	
VAR	17.68	218.43	3.52	212.66	0.00	0.00	5.33	2.01	[illegible]	6.44	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1470HSTE UTIL
AVG	92.10	36.74	36.95	34.65	29.47	0.24	33.33	27.69	32.53	0.26	
MIN	69.00	0.00	29.15	28.00	24.50	0.19	28.35	24.65	27.95	0.19	
MAX	132.00	40.00	40.30	41.20	33.25	1.02	39.35	31.50	41.15	0.87	
STD	20.79	5.74	2.60	2.33	1.82	0.11	3.32	2.16	3.06	0.11	
VAR	432.02	32.92	6.77	5.42	3.32	0.01	10.99	4.64	9.37	0.01	
COUNT	114.00	114.00	114.00	1.00	114.00	1.00	114.00	114.00	114.00	114.00	1430HASR D/RI
AVG	97.00	35.76	33.72	33.00	33.64	0.40	37.14	29.57	34.84	0.24	
MIN	81.00	29.60	28.25	33.00	28.45	0.40	29.15	24.50	28.00	0.19	
MAX	103.00	38.80	36.10	33.00	35.15	0.40	40.30	33.25	41.20	1.02	
STD	5.07	1.89	1.43	0.00	1.86	0.00	2.41	1.72	2.32	0.11	
VAR	25.69	3.59	2.04	0.00	3.44	0.00	5.81	2.97	5.40	0.01	
COUNT	114.00	114.00	114.00	114.00	114.00	1.00	114.00	114.00	114.00	114.00	1562HSTE D/TR
AVG	86.87	26.81	41.99	27.22	45.06	0.40	35.11	29.50	35.48	0.94	
MIN	80.00	0.00	38.50	0.00	32.80	0.40	32.60	26.00	29.50	0.26	
MAX	94.00	35.30	46.20	35.40	66.90	0.40	37.10	32.00	47.30	3.21	
STD	3.46	13.42	1.73	13.61	7.05	0.00	0.74	0.93	2.20	0.60	
VAR	11.87	179.98	2.99	185.31	49.75	0.00	0.55	0.87	4.82	0.36	

FILE NAME:STEWART SUMMARY

HEAT STRESS ANALYSIS OF DIESEL POWERED VEHICLE OPERATORS

INPUT PARAMETERS

APPENDIX J
LOCALITY :83 TM3
BAR PRESS: 106 kPa
DATE : DECEMBER 1990

TIME	HEARTRATE	TEMP SKIN	Tg	TEMP SKIN	Tdb	T JACKET	Tg	Tpwb	Tdb	Airspeed	
HR:MIN	b/min	celsius	celsius	celsius	celsius	celsius	celsius	celsius	celsius	m/s	
COUNT	2158.62	1088.47	910.70	662.40	081.36	123.97	1161.05	1074.02	1139.64	813.15	
AVG	94.48	41.38	32.78	25.12	27.55	0.39	38.71	33.51	37.61	16.37	
MIN	292.12	118.70	101.44	69.98	83.97	1.25	119.21	103.24	115.09	2.33	
MAX	306.12	130 29	105.49	76.04	89.65	1.28	124.74	107.68	123.79	56.77	
STD	246.55	104.96	02.93	59.41	65.04	0.96	102.51	90.03	101.05	54.42	
VAR	255.35	158.80	83.22	113.98	71.37	0.94	103.64	90.28	103.61	55.12	
COUNT	114.00	114.00	114.00	1.00	1.00	1.00	114.00	114.00	114.00	114.00	1413CST LHD
AVG	98.81	10.86	39.89	33.00	43.00	0.40	45.28	33.02	47.24	5.15	
MIN	90.00	0.00	29.30	33.00	43.00	0.40	30.00	25.70	29.50	0.20	
MAX	115.00	48.30	45.90	33.00	43.00	0.40	51.00	36.20	54.90	28.01	
STD	4.72	9.61	4.20	0.00	0.00	0.00	6.06	2.86	6.79	8.53	
VAR	22.30	92.40	17.66	0.00	0.00	0.00	36.78	8.19	46.14	72.81	
COUNT	114.00	114.00	114.00	1.00	1.00	1.00	114.00	114.00	114.00	114.00	1562CST D/TRU
AVG	98.81	10.86	39.89	33.00	43.00	0.40	45.28	33.02	47.24	5.16	
MIN	90.00	0.00	29.30	33.00	43.00	0.40	30.00	25.70	29.50	0.20	
MAX	115.00	48.30	45.90	33.00	43.00	0.40	51.00	36.20	54.90	28.01	
STD	4.72	9.61	4.20	0.00	0.00	0.00	6.06	2.86	6.79	8.53	
VAR	22.30	92.40	17.66	0.00	0.00	0.00	36.78	8.19	46.14	72.81	
COUNT	558.82	389.18	364.96	101.00	131.00	3.20	397.13	333.97	412.57	342.71	
AVG	77.66	40.86	41.55	19.00	24.71	0.37	46.92	36.14	49.40	33.41	
MIN	76.40	39.31	40.04	19.00	24.71	0.37	44.73	35.10	46.87	32.70	
MAX	79.97	46.21	42.41	19.00	24.71	0.37	47.73	36.60	50.50	36.67	
STD	64.22	40.68	36.45	14.29	18.57	0.31	41.31	31.83	43.62	33.89	
VAR	66.73	62.51	38.37	14.29	18.57	0.31	45.70	32.59	49.24	43.07	

BASIC INPUT DATA , METABOLIC WORK RATE AND PSYCHROMTERIC DATA

METABOLIC HEAT PRODUCTION : PSYCHROMETRIC DATA

HEARTRATE b/m	OXYGEN CONSUMPTION Qr VO2 BM	Qr VO2 HR	OBSERVA TIME as per input	WORK RATE W W/m2	VAP PRESS 'Pa' kPa	VAP PRESS 'Pa' mmHG	REL HUM RH %	TEM' RAD Tr C	METABOLIC HEAT M W/M2		
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1419HSTE LHD
AVG	3.59	8.86	113.00	158.21	4.07	2.99	58.41	42.42	214.10	0.89	
MIN	3.59	6.51	0.00	124.99	2.82	0.72	39.69	35.55	192.57	0.19	
MAX	3.59	12.29	226.00	206.87	4.63	8.16	75.77	49.00	245.63	4.31	
STD	0.00	1.10	65.82	15.63	0.46	1.62	7.84	2.98	10.13	0.72	
VAR	0.00	1.22	4331.67	244.37	0.21	2.62	61.43	8.90	102.61	0.52	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1419H5ST LHD
AVG	3.59	4.01	113.00	89.48	3.55	2.76	59.94	36.63	169.56	0.67	
MIN	3.59	2.02	0.00	61.31	2.73	0.36	47.76	31.15	151.31	0.1[illegible]	
MAX	3.59	7.15	226.00	134.09	4.15	5.32	82.66	42.70	198.47	2.2[illegible]	
STD	0.00	1.35	65.82	19.12	0.38	1.13	6.76	2.45	12.39	0.53	
VAR	0.00	1.82	4331.67	365.53	0.14	1.27	45.65	6.01	153.48	0.28	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1635HSTE LHD
AVG	3.73	2.40	113.00	-4.10	3.56	0.81	75.63	32.47	154.82	0.69	
MIN	3.73	-0.12	0.00	-50.72	2.76	0.41	64.94	27.80	131.66	0.19	
MAX	3.73	3.73	226.00	20.46	4.44	1.83	81.94	38.10	167.03	4.84	
STD	0.00	0.86	65.82	15.93	0.42	0.30	3.63	2.82	7.91	0.77	
VAR	0.00	0.74	4331.67	253.63	0.18	0.09	13.19	7.97	62.62	0.59	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1413HSTE LHD
AVG	3.11	8.15	113.00	81.64	4.07	2.25	64.10	37.71	207.62	1.23	
MIN	3.11	5.87	0.00	53.78	3.19	0.28	34.99	27.15	186.68	0.21	
MAX	3.11	9.94	226.00	103.46	4.88	9.68	84.33	42.30	224.01	26.42	
STD	0.00	0.90	65.82	11.00	0.30	1.87	10.20	2.48	8.26	2.54	
VAR	0.00	0.81	4331.67	120.90	0.09	3.49	104.12	6.16	68.27	6.44	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1470HSTE UTIL
AVG	3.06	5.25	113.00	84.98	3.41	1.47	69.50	34.02	180.97	0.[illegible]6	
MIN	3.06	0.31	0.00	4.11	2.83	0.31	46.62	28.03	135.59	0.19	
MAX	3.06	13.79	228.00	224.70	4.27	5.55	83.79	41.54	259.38	0.87	
STD	0.00	4.45	65.82	72.78	0.44	0.88	6.97	3.79	40.84	0.11	
VAR	0.00	19.78	4331.67	5296.42	0.19	0.78	48.56	14.35	1668.11	0.01	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1[illegible] 0	114.00	1430HASR D/RI
AVG	3.20	6.32	113.00	86.74	3.80	1.53	68.11	37.13	1[illegible]0.78	0.24	
MIN	3.20	2.87	0.00	18.89	2.77	0.37	49.33	28.83	159.17	0.19	
MAX	3.20	7.58	226.00	111.67	4.80	4.68	81.56	40.30	202.40	1.[illegible]2	
STD	ERR	1.08	65.82	21.38	0.39	0.78	5.58	2.42	9.96	0.11	
VAR	0.00	1.18	4331.67	457.05	0.15	0.61	31.14	5.86	99.21	0.01	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1562HSTE D/TR
AVG	2.9[illegible]	4.13	113.00	86.76	3.72	2.04	64.86	35.10	170.70	0.94	
MIN	2.94	2.66	0.00	60.50	2.94	0.40	31.66	32.60	157.20	0.26	
MAX	2.94	5.66	226.00	114.02	4.46	12.53	81.46	37.10	184.71	3.21	
STD	0.00	0.74	65.82	13.17	0.22	1.36	7.66	0.76	6.77	0.60	
VAR	0.09	0.54	4331.67	173.45	0.05	1.86	58.67	0.58	45.83	0.36	

BASIC INPUT DATA , METABOLIC WORK RATE AND PSYCHROMTERIC DATA

	METABOLIC HEAT PRODUCTION				PSYCHROMETRIC DATA				METABOLIC		
HEARTRATE	OXYGEN CONSUMPTION		OBSERVA	WORK RATE	VAP PRESS	VAP PRESS	REL HUM	TEMP RAD	HEAT		
	Qr	Qr	TIME as	W	'Pa'	'Pa'	RH	Tr	M		
b/m	VO2 BM	VO2 HR	per input	W/m2	kPa	mHG	%	C	W/M2		
COUNT	820.14	879.17	15007.45	7466.25	832.68	826.53	1535.91	1167.76	4371.96	813.15	
AVG	17.54	20.26	601.97	334.31	17.81	17.23	50.77	39.02	211.57	16.37	
MIN	55.07	62.65	2078.78	1031.93	55.53	53.32	176.04	119.15	655.48	2.33	
MAX	55.00	65.65	2207.92	1078.26	56.52	57.65	197.05	124.64	682.99	55.77	
STD	ERR	61.16	2116.39	1006.64	54.16	54.38	155.23	102.12	565 94	54.4[illegible]	
VAR	ERR	60.76	4554.02	1149.41	54.00	54.82	185.73	103.30	600.96	55.12	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1413CST LHD
AVG	3.11	6.68	113.00	63.73	4.12	8.72	39.72	45.28	194.16	5.15	
MIN	3.11	4.80	0.00	40.70	2.72	0.75	28.64	30.00	176.85	0.20	
MAX	3.11	10.15	226.00	106.07	4.89	13.63	76.27	51.00	225.98	28.01	
STD	0.00	1.01	65.82	12.35	0.52	3.29	12.17	6.08	9.28	8.53	
VAR	0.00	1.02	4331.67	152.45	0.27	10.81	147.99	36.91	86.09	72.81	
COUNT	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	1562CST D/TRU
AVG	2.94	4.72	113.00	56.80	3.75	4.26	52.40	ERR	176.11	5.15	
MIN	2.94	2.66	0.00	33.32	3.11	1.20	34.80	ERR	157.20	0.20	
MAX	2.94	9.08	226.00	103.40	4.77	9.93	70.80	ERR	216.15	28.01	
STD	0.00	1.26	65.82	13.76	0.38	1.79	7.23	ERR	11.57	8.53	
VAR	0.00	1.59	4331.67	189.34	0.14	3.22	52.32	ERR	133.95	72.81	
COUNT	237.32	251.67	4964.48	603.30	240.61	265.19	532.78	397.26	920.35	342.71	
AVG	18.04	20.34	709.07	77.87	18.61	22.21	67.31	ERR	140.35	33.41	
MIN	18.01	19.77	692.93	73.53	18.47	21.13	66.61	ERR	135.07	32.70	
MAX	17.99	20.38	725.21	82.48	18.76	22.45	72.63	ERR	140.69	36.67	
STD	17.54	19.11	702.33	69.30	18.11	20.76	62.77	ERR	110.06	33.89	
VAR	17.54	19.19	1311.74	94.58	18.06	20.75	68.51	ERR	127.87	43.07	

Heat sources influencing the operator: (refer page 47)

$$q_t = q_1 + q_2 - q_3$$

where:

q_t is the heat in the cabin
q_1 is the heat from the engine
q_2 is the metabolic heat from the driver
q_3 is the heat loss to the ambient air over 50% ofthe cabin wall

Heat from the engine (q_1):
The heat flow from the engine to the steel substraight (the cabin wall) is governed by the four basic heat transfer mechanisms. They are convection, conduction, radiation and evaporation.
The heat generated during fuel combustion is usually included in an energy balance and expressed as percentages of the energy supplied by the fuel:
brake power + heat to the engine cooling air + the energy of the exhaust + unaccounted losses obtained by difference, and which include radiation and convection losses.
Heat generated by the engine flows via the cooling air to the cabin wall. The following formulae show the heat flow from the outer skin of the cabin wall, through the wall, via the cabin air,through the other cabin wall to the ambient air

and:

$$q_1 = q_r + q_{c1} + q_{c2} - q_e$$

where:

q_r is the radiant heat transfer over the total area of the cabin (Whillier,1982)
q_{c1} is the convective heat transfer through the air in the cabin
q_{c2} is the conductive heat transfer from the engine compartment via the steel substrait to the cabin
q_e is the heat loss due to evaporation of any liquid in the cabin, this is however neglected as condition as extremely dry in the cabin. It is also difficult to quantify.

and:

$$q_r = 5{,}67\ (T_1/100)^4-(T_2/100)^4*A_2*F_{ev}$$

where:

q_r is the radiant heat ex the engine in W/m^2.
T_1 is the absolute temperature of the air on the engine side of the cabin wall in K
T_2 is the absolute temperature of the air in the drivers cabin in K
5,67 is Stefan Boltzman constant for radiant heat heat transfer
A_2 is the total area of the cabin wall in m^2
$F_{ev}$is emissivity or view factor in terms of T_2

and:

$$T_2 = \quad 1/(^1/e_1+(A1/A2(^1/e_2-1)))$$

where:

e is the view factor of the heat transfer plane

and:

$$qc_1 = hc\ A\ (t_{wall}-t_{cabin}) \quad \text{in } W/m^2$$

where:

hc is the convective heat transfer coeff and is dependant on the ambient conditions in the cabin in terms of temperature and airflow.

Also hc $\quad 5680\ (1+0{,}015t)*v^{0,8}/d^{0,2}$
with airflow in the cabin
or

$hc = 1{,}4\ (t_{wall}-t_{cabin})^{1/3}$
with natural convection in basically still air

NOTE:

Due to the contact between A_2 and A_3 it will be necessary to use the log mean temperature difference (LMTD) when expressing the t_{wall}.

where:

$$LMTD = (t_{A_2} - t_{A_3})/\log_e(t_{A_2}/t_{A_3})$$

and : t_{A_2} is the average temperature of the steel substrait also called the cabin wall, on the engine side of the cabin in ° celcius.

t_{A_3} is the average temperature of the steel substrait also called the drivers cabin, on the ambient air side of the cabin in ° celcius.

and:

q_{c2} is the conductive heat transfer

and $q_{c2} = 2 \quad k \; T \; (t_{ae} - t_{ac})$

where:

k is the thermal conductivity of the steel substraight @ 45,0 W/m^2(neglecting the paintwork on the steel

T is the temperature of the steel in kelvin

t_{ae} is the engine compartment air temperature in ° celcius.

t_{ac} is the air temperature in the cabin in ° celcius

Heat from the vehicle operator (q_2):

This heat source has been discussed in appendix H.

Heat loss to ambient air (q_3):

This mechanism is the inverse to the heat from the engine (q_1), with the exception that the governing factor is the ambient air temperature.