UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

ENVIRONMENTAL ASPECTS IN TRACKLESS MECHANISED MINING

HENNING J FOURIE
ENVIRONMENTAL ASPECTS IN TRACKLESS MECHANISED MINING METHODS.

HENNIE J. FOURIE

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

JOHANNESBURG 1991
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

30/4

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
III

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.
IV

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, the 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.

Investigations 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 TNNM 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 TMM 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 aggressiveness.

Economical air factors to ventilate areas where TMM 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 TBM.

Lastly, the development and introduction of jet fan technology was undertaken. This is an unexplored area for possible future research in TMM. 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 TMM must be done.

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

I would like to thank Johannesburg Consolidated Investments for the permission granted to publish this research project.

Professor A R Adams for his patience during the preparation period and the valuable advice offered.

A special word of thanks to Marie Richards and Judith Matthee for the typing of this document.
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Chapter 1:

Heatload Factors for Diesel Engines

1.1 PROBLEM

The low thermal efficiency of the diesel internal combustion engine has a marked influence on the underground environment. The advantages in maneuverability of a diesel powered mining vehicle (to the mining fraternity over that of an electrically driven unit is evident. The low thermal efficiency of the diesel engines play a major role in the cost of a trackless mining project when considering refrigeration of 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:

\[ kd = \left( \frac{87.0}{p} \right)^{0.65} \times \left( \frac{t + 273}{298} \right)^{0.5} \]

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 utilisation 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 temperatures.

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

![Graph showing performance of indirect injection engine with 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

Activities
- preparation
- loading 20% up
- loading horizontally
- 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 temperatures 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

EXHAUST TEMPERATURE °C 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 TMMN 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 efficiency, 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 (CChRO) involving locomotives and LHD's. These findings relate the heat from locomotives as 1.5 times the rated power. On the other 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 explanation of the mining methods.

<table>
<thead>
<tr>
<th>Mining Method</th>
<th>KW heat/kton Rock Broken per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut and fill</td>
<td>Diesel 42.8</td>
</tr>
<tr>
<td></td>
<td>Electric 32.5</td>
</tr>
<tr>
<td>Vertical Crater Retreat</td>
<td>Diesel 14.8</td>
</tr>
<tr>
<td></td>
<td>Electric 41.5</td>
</tr>
<tr>
<td>Narrow Reef</td>
<td>Diesel 37.0</td>
</tr>
<tr>
<td></td>
<td>Electric 79.4</td>
</tr>
<tr>
<td>Development</td>
<td>Diesel 37.0</td>
</tr>
<tr>
<td></td>
<td>Electric 32.3</td>
</tr>
</tbody>
</table>

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 TMMK 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.

<table>
<thead>
<tr>
<th>Source</th>
<th>kW heat/ kW rated</th>
<th>Cal Value kW/l</th>
<th>Fuel used 1/ton</th>
<th>1 Fuel/ hour per rated kW MJ/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>McPherson</td>
<td>2,83</td>
<td>34 000</td>
<td>0,545</td>
<td>0,30</td>
</tr>
<tr>
<td>Fourie</td>
<td>1,475</td>
<td>36 538</td>
<td>0,545</td>
<td>0,51</td>
</tr>
<tr>
<td>Unsted : LED fuel</td>
<td>1,88</td>
<td>38 273</td>
<td>0,67</td>
<td>0,19</td>
</tr>
<tr>
<td>LOCO fuel</td>
<td>2,10</td>
<td>37 528</td>
<td>0,89</td>
<td>0,21</td>
</tr>
<tr>
<td>Surface fuel</td>
<td>1,71</td>
<td>38 377</td>
<td>0,71</td>
<td>0,17</td>
</tr>
</tbody>
</table>

Table 1.3 - Summary of planning figures

In the case of McPherson and Fourie, US diesel fuel and LED (low emission diesel) fuel was used respectively. LOCO fuel is diesel fuel marketed specifically 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 the various mining methods employed in TMMK. 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 CCNRO 'ENVIRON' program and figures derived for the various TMXNM 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 emissions" mean "smoke and nitrous oxide limiting" power output in the tables 1.4 to 1.7.
The table below presents the power derated kW for various vehicles used in the project. The deration is based on gas emissions and is not done underground as of yet. The temperature and elevation used correspond to that of the project to be analyzed.

**TEMPERATURE AVERAGE = 29.5/38.5°C**

**BAR PRESSURE = 100.5**

*Table 1.4 - 58 Level TMMW vehicle float*

<table>
<thead>
<tr>
<th>Code No</th>
<th>Prod Grp</th>
<th>Description</th>
<th>Manufact</th>
<th>Model</th>
<th>Spec kW Rate</th>
<th>Cyl</th>
<th>Power* Derated kW</th>
<th>Total No.</th>
<th>Powd</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW 1</td>
<td>LHD</td>
<td>Wagner LHD HV Dav</td>
<td>3.5T</td>
<td>3.5m3</td>
<td>144.00</td>
<td>8.00</td>
<td>134.35</td>
<td>2.00</td>
<td>269</td>
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<tr>
<td>LW 2</td>
<td>LHD</td>
<td>Wagner LHD HV Dav</td>
<td>60</td>
<td>6.0m3</td>
<td>180.00</td>
<td>10.00</td>
<td>167.94</td>
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<tr>
<td>GH 5</td>
<td>LHD</td>
<td>KHH LHD IMG Eng</td>
<td>LF12</td>
<td>8.0m3</td>
<td>16.00</td>
<td>12.00</td>
<td>201.53</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>TW 1</td>
<td>Truck</td>
<td>Wagner D/Truck HV Dav</td>
<td>08</td>
<td>1.8Ton</td>
<td>190.00</td>
<td>10.00</td>
<td>167.94</td>
<td>0.00</td>
<td>0</td>
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<tr>
<td>UW 2</td>
<td>Util</td>
<td>Wagner U/Veh HV Dav</td>
<td>UT49A</td>
<td>SC198L</td>
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<td>6.00</td>
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<td>UN 1</td>
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<td>58.78</td>
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<tr>
<td>UVY/US1</td>
<td>Util</td>
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<tr>
<td>UC 1</td>
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<td>Scaler Ji Case</td>
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<td>Lub Cassette HV Dav</td>
<td>000</td>
<td>Util</td>
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<td>RE 1</td>
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<td>Secoma/Bolt Sec</td>
<td>D/Rig</td>
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<td>6.00</td>
<td>58.78</td>
<td>0.00</td>
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<td>5.00</td>
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<tr>
<td>DF 2</td>
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<td>D/Rig</td>
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<td>5.00</td>
<td>48.52</td>
<td>0.00</td>
<td>97</td>
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**TOTAL POWER DERATED kW = 803**
<table>
<thead>
<tr>
<th>Code No</th>
<th>Prod Grp</th>
<th>Description</th>
<th>Manufact</th>
<th>Model</th>
<th>Spec</th>
<th>kW Rate</th>
<th>Cyl</th>
<th>Power* Derated</th>
<th>Total Powd</th>
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<td>8.00</td>
<td>131.29</td>
<td>2.00</td>
<td>263</td>
</tr>
<tr>
<td>LW 2</td>
<td>LHD</td>
<td>Wagner LHD HV Dav</td>
<td>6C</td>
<td>6.0m3</td>
<td>180.00</td>
<td>10.00</td>
<td>164.11</td>
<td>2.00</td>
<td>328</td>
</tr>
<tr>
<td>GH 5</td>
<td>LHD</td>
<td>CHH LHD XM Eng</td>
<td>LV12</td>
<td>8.0m3</td>
<td>216.00</td>
<td>12.00</td>
<td>196.93</td>
<td>1.00</td>
<td>197</td>
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<tr>
<td>TW 1</td>
<td>Truck</td>
<td>Wagn D/Truck HV Dav</td>
<td>18Ton</td>
<td></td>
<td>100.00</td>
<td>10.00</td>
<td>164.11</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>DW 2</td>
<td>Util</td>
<td>Wagn U/Veh HV Dav</td>
<td>TU45A</td>
<td>SC198L</td>
<td>63.00</td>
<td>6.00</td>
<td>57.44</td>
<td>2.00</td>
<td>115</td>
</tr>
<tr>
<td>UN 1</td>
<td>Util</td>
<td>VT Veh Normat</td>
<td>FR1000</td>
<td></td>
<td>63.00</td>
<td>6.00</td>
<td>57.44</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>UY1/US1</td>
<td>Util</td>
<td>SVM3000 Spec Veh</td>
<td>SVM3000</td>
<td>Jeep</td>
<td>32.00</td>
<td>3.00</td>
<td>29.18</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>UG 1</td>
<td>Util</td>
<td>Scaler JI Case</td>
<td>5800G</td>
<td>Scaler</td>
<td>50.00</td>
<td>4.00</td>
<td>46.59</td>
<td>3.00</td>
<td>137</td>
</tr>
<tr>
<td>EN 1</td>
<td>Util</td>
<td>Lub Cassetto HV Dav</td>
<td>000</td>
<td>Util</td>
<td>63.00</td>
<td>6.00</td>
<td>57.44</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>Case</td>
<td>Util</td>
<td>Grader Case</td>
<td></td>
<td>Grader</td>
<td>50.00</td>
<td>4.00</td>
<td>45.59</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>RE 1</td>
<td>Rigs</td>
<td>Secoma/ R/Bolt Sec</td>
<td></td>
<td>Rig</td>
<td>63.00</td>
<td>6.00</td>
<td>57.44</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>DA 1</td>
<td>Rigs</td>
<td>Boomser A/Copco</td>
<td></td>
<td>D/Rig</td>
<td>52.00</td>
<td>5.00</td>
<td>47.41</td>
<td>2.00</td>
<td>95</td>
</tr>
<tr>
<td>DF 2</td>
<td>Rigs</td>
<td>Single Boom Seco</td>
<td></td>
<td>D/Rig</td>
<td>52.00</td>
<td>5.00</td>
<td>47.41</td>
<td>0.00</td>
<td>0</td>
</tr>
</tbody>
</table>

TOTAL POWER DERATED = kW 134

* = Power deration based maximum gas emission - 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 THMM vehicle fleet
<table>
<thead>
<tr>
<th>Code</th>
<th>Prod Grp</th>
<th>Description</th>
<th>Manufact</th>
<th>Model</th>
<th>Spec kW Rate</th>
<th>Cyl</th>
<th>Power* Derated</th>
<th>Total No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW 1</td>
<td>LHD</td>
<td>Wagner LHD</td>
<td>HV Dev</td>
<td>3.5T</td>
<td>144.00</td>
<td>8.00</td>
<td>132.48</td>
<td>1.00 132</td>
</tr>
<tr>
<td>LW 2</td>
<td>LHD</td>
<td>Wagner LHD</td>
<td>HV Dev</td>
<td>6C</td>
<td>190.00</td>
<td>10.00</td>
<td>165.60</td>
<td>1.00 166</td>
</tr>
<tr>
<td>GH 5</td>
<td>LHD</td>
<td>IMG LHD</td>
<td>LF12</td>
<td>6.0m3</td>
<td>216.00</td>
<td>12.00</td>
<td>198.72</td>
<td>0.00 0</td>
</tr>
<tr>
<td>TW 1</td>
<td>Truck</td>
<td>Wagner D/Truck</td>
<td>HV Dev</td>
<td>18' Ton</td>
<td>190.00</td>
<td>10.00</td>
<td>165.60</td>
<td>0.00 0</td>
</tr>
<tr>
<td>UW 2</td>
<td>Util</td>
<td>Wagner U/Veh</td>
<td>HV Dev</td>
<td>UP45A</td>
<td>63.00</td>
<td>6.00</td>
<td>57.96</td>
<td>2.00 116</td>
</tr>
<tr>
<td>UN 1</td>
<td>Util</td>
<td>VT Veh</td>
<td>Normet</td>
<td>PE1000</td>
<td>63.00</td>
<td>6.00</td>
<td>57.96</td>
<td>0.00 0</td>
</tr>
<tr>
<td>UW1/US1</td>
<td>Util</td>
<td>SVM3000</td>
<td>Spec Veh</td>
<td>SVM3000</td>
<td>32.00</td>
<td>3.00</td>
<td>29.44</td>
<td>0.00 0</td>
</tr>
<tr>
<td>UG 1</td>
<td>Util</td>
<td>Scaler</td>
<td>JI Case</td>
<td>880G</td>
<td>50.00</td>
<td>4.00</td>
<td>46.00</td>
<td>0.00 0</td>
</tr>
<tr>
<td>EW 1</td>
<td>Util</td>
<td>Lub Cassetto</td>
<td>HV Dev</td>
<td>000</td>
<td>63.00</td>
<td>6.00</td>
<td>57.96</td>
<td>0.00 0</td>
</tr>
<tr>
<td>Case</td>
<td>Util</td>
<td>Grader</td>
<td>Case</td>
<td></td>
<td>50.00</td>
<td>4.00</td>
<td>46.00</td>
<td>0.00 0</td>
</tr>
<tr>
<td>RE 1</td>
<td>Rigs</td>
<td>Secoma/R/Bolt</td>
<td>Sec</td>
<td>Rig</td>
<td>63.00</td>
<td>6.00</td>
<td>57.96</td>
<td>0.00 0</td>
</tr>
<tr>
<td>DA 1</td>
<td>Rigs</td>
<td>Bomco</td>
<td>DA/Copco</td>
<td>Rig</td>
<td>52.00</td>
<td>5.00</td>
<td>47.84</td>
<td>1.00 48</td>
</tr>
<tr>
<td>DF 2</td>
<td>Rigs</td>
<td>Single Boom</td>
<td>B/Seco</td>
<td>Rig</td>
<td>52.00</td>
<td>5.00</td>
<td>47.84</td>
<td>0.00 48</td>
</tr>
</tbody>
</table>

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 = 29.5/38.8°C
BAR PRESSURE = 102.5

Table 1.6 - 65-2W TMWM vehicle fleet
17
<table>
<thead>
<tr>
<th>Code No</th>
<th>Prod Grp</th>
<th>Description</th>
<th>Manufact</th>
<th>Model</th>
<th>Spec</th>
<th>kW Rate</th>
<th>Cyl</th>
<th>Power Derated</th>
<th>Total No.</th>
<th>POWd</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW 1</td>
<td>LHD</td>
<td>Wagner LHD</td>
<td>HV Dav</td>
<td>3-ST</td>
<td>3.5m³</td>
<td>144.00</td>
<td>8.00</td>
<td>127.68</td>
<td>3.00</td>
<td>343</td>
</tr>
<tr>
<td>LW 2</td>
<td>LHD</td>
<td>Wagner LHD</td>
<td>HV Dav</td>
<td>6C</td>
<td>6.0m³</td>
<td>180.00</td>
<td>10.00</td>
<td>159.60</td>
<td>3.00</td>
<td>479</td>
</tr>
<tr>
<td>GH 5</td>
<td>LHD</td>
<td>GHH LHD</td>
<td>IMG Eng</td>
<td>LF12</td>
<td>8.0m³</td>
<td>216.00</td>
<td>12.00</td>
<td>191.53</td>
<td>1.00</td>
<td>12</td>
</tr>
<tr>
<td>TW 1</td>
<td>Truck</td>
<td>Wagner D/Truck</td>
<td>HV Dav</td>
<td>DB</td>
<td>1STon</td>
<td>180.00</td>
<td>10.00</td>
<td>159.60</td>
<td>3.00</td>
<td>479</td>
</tr>
<tr>
<td>UW 2</td>
<td>Util</td>
<td>Wagner U/Veh</td>
<td>HV Dav</td>
<td>UT45A</td>
<td></td>
<td>62.00</td>
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<td>168</td>
</tr>
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<td>UN 1</td>
<td>Util</td>
<td>VT Veh</td>
<td>Normat</td>
<td>PK1000</td>
<td></td>
<td>63.00</td>
<td>6.00</td>
<td>55.86</td>
<td>1.00</td>
<td>96</td>
</tr>
<tr>
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<td>Util</td>
<td>SVM3000</td>
<td>Spec Veh</td>
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<td>0</td>
</tr>
<tr>
<td>UG 1</td>
<td>Util</td>
<td>Scaler</td>
<td>JT Case</td>
<td>580G</td>
<td></td>
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<td>4.00</td>
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<td>Util</td>
<td>Lub Cassette</td>
<td>HV Dav</td>
<td>000</td>
<td></td>
<td>63.00</td>
<td>6.00</td>
<td>55.86</td>
<td>1.00</td>
<td>56</td>
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<td>Case</td>
<td>Util</td>
<td>Grader</td>
<td>Case</td>
<td></td>
<td></td>
<td>50.00</td>
<td>4.00</td>
<td>44.33</td>
<td>1.00</td>
<td>44</td>
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<td>Secoma/</td>
<td>Eimac</td>
<td>Rig</td>
<td></td>
<td>63.00</td>
<td>6.00</td>
<td>55.86</td>
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<td>Sec</td>
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<td>B/Seco</td>
<td>Rig</td>
<td></td>
<td>52.00</td>
<td>5.00</td>
<td>46.11</td>
<td>0.00</td>
<td>0</td>
</tr>
</tbody>
</table>

TOTAL POWER DERATED = kW 2464

* = Power deration based on maximum exhaust gas emission 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 TMMX vehicle fleet

18
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.

<table>
<thead>
<tr>
<th>Project</th>
<th>1/kW/h</th>
<th>kW der</th>
<th>Oper hrs</th>
<th>1/tonne</th>
<th>kW/kTonn</th>
<th>kWd/kTm</th>
<th>Mining Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 - 2W</td>
<td>0.01</td>
<td>462</td>
<td>20415</td>
<td>0.81</td>
<td>31.24</td>
<td>43.55</td>
<td>(a)</td>
</tr>
<tr>
<td>68 Lev</td>
<td>0.05</td>
<td>803</td>
<td>21376</td>
<td>1.01</td>
<td>39.12</td>
<td>61.10</td>
<td>(a)</td>
</tr>
<tr>
<td>85 Lev</td>
<td>0.01</td>
<td>2464</td>
<td>165193</td>
<td>0.57</td>
<td>21.81</td>
<td>62.12</td>
<td>(a - d)</td>
</tr>
<tr>
<td>70 Lev</td>
<td>0.015</td>
<td>1134</td>
<td>58309</td>
<td>0.44</td>
<td>17.07</td>
<td>30.11</td>
<td></td>
</tr>
</tbody>
</table>

Weighted Average 0.0127 876 929711 0.682 27.31 49.22

| TOTALS    | 4803   | 295293 |

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

REMARKS

1. Previous analysis (1986) show

<table>
<thead>
<tr>
<th>Mining Method</th>
<th>kWd/kTonne/Month</th>
</tr>
</thead>
</table>
   a) Cut & fill mining | 42.87 |
   b) Vertical crater retreat | 14.3 |
   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.

19
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.

<table>
<thead>
<tr>
<th>Mining Method</th>
<th>kW Heat / kTon Rock Broken/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut and fill</td>
<td>64.03</td>
</tr>
<tr>
<td>Vert crater retreat</td>
<td>22.02</td>
</tr>
<tr>
<td>Narrow reef</td>
<td>55.50</td>
</tr>
<tr>
<td>Development</td>
<td>55.50</td>
</tr>
</tbody>
</table>

Table 1.9 - Temperature Independent Heat Loads Corrected
5. DISCUSSION

Due to the difficulty of simulating a TMGM 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 (pág. 13). 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 TMGM 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 eventually 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 an 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

HEATLOAD $k^3/\text{kt} \cdot \text{month}$

VIRGIN ROCK TEMPERATURE $^\circ C$

TMMM

- CUT & FILL
- VERT CRATER RETREAT
- NARROW STOPING
- DEVELOPMENT ENDS

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

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FIG 1.4
HEAT PRODUCTION RATE - TID
TMMM - VARIOUS MINING METHODS

HEATLOAD kW (Thousands)

ROCK PRODUCTION RATE ktonne / month

TMMM
- CUT & FILL
- NARROW STOPING
- VERT CRATER RETREAT
- DEVELOPMENT ENDS

BASED ON ENVIRON HEAT FLOW SIMULATIONS
TID = TEMPERATURE INDEPENDENT HEAT LOAD
FIG 1.5
HEAT PRODUCTION RATE - TOTAL
TMMM - VARIOUS MINING METHODS

HEAT LOAD kW / ktonne month

250
200
150
100
50

0

28 30 32 34 36 38 40 42 44 46 48 50

VIRGIN ROCK TEMPERATURE °C

TMMM

- CUT & FILL
- NARROW STOPING

- VERT CRATER RETREAT
- DEVELOPMENT ENDS

BASED ON ENVIRON HEAT FLOW SIMULATIONS
TOTAL • TID • TD HEAT LOAD FACTORS
25  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/m²):

**Human body heat 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 phenomenon 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 AGGRESSIVE BEHAVIOUR

% OF YEARLY TOTAL

WINTER  SPRING  SUMMER  FALL

SEASON

TYPES AGGRESSION

- UPAISING  FAMILY DISTURBANCE  ASSAULT
- RAPE  VIOLENT CRIME

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. Especially 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/m²). See the relation of these operators to that in the other work categories in table 2.1.

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

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/m².

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

32
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 diminishing importance of this wetbulb temperature in hou 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

WET-BULB TEMPERATURE C

RADIANT HEAT OR DRY-BULB TEMPERATURE C

AIRSPEED

- 2,0 m/s
- 1,0 m/s
- 0,5 m/s
- 0,2 m/s

moderate work (180 W/m²), ta=tr,P=100KPa
sweat rate = 0,45kg/m²h
mean skin temperature = 35,1 °C  fig 2.2
2.2 LITERATURE SURVEY

The variance between the psychrometric wetbulb temperature (tpwb) and wind speed 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 wind speed
WETBULB TEMPERATURE AND WIND SPEED REQUIRED TO COMPENSATE FOR AN ELEVATION IN RADIANT AND DRYBULB TEMPERATURE

WET-BULB TEMPERATURE °C

RADIANT HEAT OR DRY-BULB TEMPERATURE °C

AIRSPEED
- 2.0 m/s
- 1.0 m/s
- 0.5 m/s
- 0.2 m/s

Moderate work (180 W/m²), t=tr,t=100kPa
Sweat rate= 0.25 kg/m²h
Mean skin temperature=35.1 °C
fig 2.3
Little information exists when this gap increases. Stewart (1984:948) 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

WET-BULB TEMPERATURE °C

RADIANT HEAT ABOVE DRY-BULB TEMPERATURE

moderate work (180 W/m²), ta=tr, t=100KPa
sweat rate = 0,46kg/m²h
mean skin temperature = 36,1 °C = lg 2,4

AIRSPEED
- 2,0 m/s
- 1,0 m/s
- 0,5 m/s
- 0,2 m/s
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 COMBO'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 (1995) 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 (Freq) 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 derivative 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 (HSINH & DC)

Literature on these indices have been consulted, with specific reference to Kawan (1981:611) using effective heat strain index (EHSI) and the wetbulb globe temperature (WBST) 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 the above using data from the specific research and directives from OSHA/SH (1974).

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

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Power Rating</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load-haul dumper Type 1</td>
<td>2 x 144 kW</td>
<td>Wagner</td>
</tr>
<tr>
<td>Load-haul dumper Type 2</td>
<td>1 x 216 kW</td>
<td>CHH</td>
</tr>
<tr>
<td>Dumptruck 10 ton (DT)</td>
<td>3 x 180 kW</td>
<td>Wagner</td>
</tr>
<tr>
<td>Utility Vehicle (UV)</td>
<td>1 x 63 kW</td>
<td>Wagner</td>
</tr>
</tbody>
</table>

Vehicles used during the evaluation.

The monitoring period consisted of two (2) days per operator at average 7½ hours per day continuous driving.
Figure 3.6 - Vehicles used during the Evaluation
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, detrimental 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 divided into:

\[ q_{\text{cabin}} = q_1 + q_2 - q_3 \]

Where:
- \( q_1 \) is heat from engine impinging on conditions in the cabin, W/m².
- \( q_2 \) is heat generated by the driver, W/m².
- \( q_3 \) is heat loss due to ambient air cooling effect, W/m².
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 100).

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 m².

Heart rates were taken to determine VO₂ max which is the maximum oxygen uptake and the metabolic work rate.

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

- **Physiological parameters**
  Portable heart rate monitors (Type Oxford Medilog MR18) 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 GRANT data logger (Type Squirrel : No 8216). These instruments are shown in figure 2.6.

- **Environmental parameters**
  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 8218) were used to collate the necessary information. These instruments are also shown in figure 3.6.
Figure 2.6 - MEDLOG 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/m². Again SCPA being the specific cooling power of the air required for cooling the metabolic heat generated.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Stress</th>
<th>WBGT (°C)</th>
<th>SCPA (W/m²)</th>
<th>Metab work rate</th>
<th>Eff Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHD Type 1</td>
<td>Y</td>
<td>32.5</td>
<td>240</td>
<td>180</td>
<td>38.2</td>
</tr>
<tr>
<td>LHD Type 2</td>
<td>Y</td>
<td>38.9</td>
<td>180</td>
<td>190</td>
<td>36.0</td>
</tr>
<tr>
<td>DT</td>
<td>N</td>
<td>35.1</td>
<td>200</td>
<td>175</td>
<td>41.7</td>
</tr>
<tr>
<td>UV</td>
<td>N</td>
<td>34.0</td>
<td>250</td>
<td>180</td>
<td>31.5</td>
</tr>
</tbody>
</table>

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 wet bulb globe temperature (WBGT) in the drivers’ cabin is reflected in the table 2.3.

<table>
<thead>
<tr>
<th>Operator Vehicle Type</th>
<th>WBGT - °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHD Type 1</td>
<td>32.5</td>
</tr>
<tr>
<td>LHD Type 2</td>
<td>38.9</td>
</tr>
<tr>
<td>DT</td>
<td>35.1</td>
</tr>
<tr>
<td>UV</td>
<td>34.0</td>
</tr>
</tbody>
</table>

Table 2.3 - WBGT Drivers’ cabin
TEMPERATURE ANALYSIS DRIVERS
PSCHY. WETBULB TEMP. AMBIENT

![Graph showing temperature analysis for different vehicle types.](Figure 2.7a)
TEMPERATURE ANALYSIS DRIVERS
DRYBULB TEMP.AMBIENT

VEHICLE TYPE
- LHD TYPE 1
- DUMPTUCK
- LHD TYPE 2
- UTILITY VEHICLE

FIG 2.7 B
TEMPERATURE ANALYSIS DRIVERS
GLOBE TEMP. AMBIENT

VEHICLE TYPE
- LHD TYPE 1
- LHD TYPE 2
- DUMPTRUCK
- UTILITY VEHICLE

56 FIG 2.7 C
TEMPERATURE ANALYSIS DRIVERS
RADIANT TEMP.AMBIENT

VEHICLE TYPE
- LHD TYPE 1
- LHD TYPE 2
- DUMPTRUCK
- UTILITY VEHICLE

FIG 2.7 D
TEMPERATURE ANALYSIS DRIVERS EFFECTIVE TEMP. AMBIENT

VEHICLE TYPE
- LHD TYPE 1
- LHD TYPE 2
- DUMPTRUCK
- UTILITY VEHICLE

Fig 2.7 E
TEMPERATURE ANALYSIS DRIVERS
CORRECTED EFFECT TEMP AMBIENT

VEHICLE TYPE
- LHD TYPE 1
- LHD TYPE 2
- DUMPTUCK
- UTILITY VEHICLE

59 FIG 2.7 F
TEMPERATURE ANALYSIS DRIVERS
WET KATA READING AMBIENT

WET KATA (mcal/cm²/sec)

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>H</th>
<th>AVG</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHD TYPE 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHD TYPE 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUMPTRUCK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTILITY VEHICLE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VEHICLE TYPE

H: High
AVG: Average
L: Low

STATISTICS

FIG 2.7 G
TEMPERATURE ANALYSIS DRIVERS
METABOLIC WORK RATE DRIVERS

WORK RATE (W/m²)

VEHICLE TYPE
- LHD TYPE 1
- LHD TYPE 2
- DUMPTUCK
- UTILITY VEHICLE

FIG 2.7 H
TEMPERATURE ANALYSIS DRIVERS
HEART RATE DRIVERS

VEHICLE TYPE
- LHD TYPE 1
- LHD TYPE 2
- DUMPTUCK
- UTILITY VEHICLE
TEMPERATURE ANALYSIS DRIVERS
RELATIVE AIRSPEED

VEHICLE TYPE

- LHD TYPE 1
- LHD TYPE 2
- DUMPTUCK
- UTILITY VEHICLE

FIG 2.7 J
TEMPERATURE ANALYSIS DRIVERS
SPECIFIC COOLING POWER OF THE AIR

COOLING POWER (W/m²)

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>AVG</th>
<th>L</th>
<th></th>
<th>H</th>
<th>AVG</th>
<th>L</th>
<th></th>
<th>H</th>
<th>AVG</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHD TYPE 1</td>
<td>274</td>
<td>238</td>
<td>60</td>
<td>LHD TYPE 2</td>
<td>264</td>
<td>183</td>
<td>102</td>
<td>DUMPTRUCK</td>
<td>272</td>
<td>191</td>
<td>76</td>
</tr>
<tr>
<td>UTILTITY VEHICLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>281</td>
<td>247</td>
<td>207</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VEHICLE TYPE

- LHD TYPE 1
- LHD TYPE 2
- DUMPTRUCK
- UTILITY VEHICLE

64

FIG 2.7 K
TEMPERATURE ANALYSIS DRIVERS
WORK RATE vs COOLING POWER OF AIR

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/m²)

VEHICLE TYPE
- □ LHD TYPE 1  □ LHD TYPE 2  □ DUMPTUCK  □ UTILITY VEHICLE

66  FIG 2.7 M
HEAT STRESS ANALYSIS OF OPERATORS
REF1419H5W - COOL CONDITION

Temperature °C & Wet bulb reading

Relative air speed m/s

AMBIENT CONDITIONS

- T wetbulb
- T drybulb
- Relative Air speed
- WET KATA

67 FIG 2.7 N
TEMPERATURE ANALYSIS DRIVERS
WETBULB GLOBE TEMPERATURE

VEHICLE TYPE
- LHD TYPE 1
- LHD TYPE 2
- DUMPTUCK
- UTILITY VEHICLE

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 driver'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 ° centigrade.

- The angle of posture of the feet in relation to the footpedals is acute. Unnecessary 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 Bruehl and Kjaer noise dosimeter.

<table>
<thead>
<tr>
<th>Operator Vehicle Type</th>
<th>Leq</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHD Type 1</td>
<td>115</td>
</tr>
<tr>
<td>LHD Type 2</td>
<td>110</td>
</tr>
<tr>
<td>DT</td>
<td>110</td>
</tr>
<tr>
<td>UV</td>
<td>98</td>
</tr>
</tbody>
</table>

*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 26.5/31.5 °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 foregoing 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.
MICROCLIMATE COOLING TRAILS LHD
COMPARISON OF CERTAIN PARAMETERS
NON COOLING CONDITION

PARAMETERS
- SKIN TEMP.
- HEART RATE
- COOL AIR TEMP.

WET-BULB TEMPERATURE

HEART RATE bpm

TIME AFTER BEGINNING OF SHIFT (min.)

NO PERSONAL AIR CONDITIONER
72
FIG 2.9
MICRO CLIMATE COOLING TRAILS LHD
COMPARISON OF CERTAIN PARAMETERS
COOLING CONDITION

PARAMETERS
- SKIN TEMP.
- HEART RATE
+ COOL AIR TEMP

TIME AFTER BEGINNING OF SHIFT

PERSONAL AIR CONDITIONER FITTED
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 vice 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/m² ± 10 W/m²) 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 \( >115 \text{ W/m}^2 <180 \text{ W/m}^2 \).
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 in turn develops the cardio/vascular capabilities.
PHYSIOLOGICAL PERFORMANCE OPERATORS TM MM VEHICLES

HEARTRATE bpm

METABOLIC WORKRATE W/m²

77 FIG 2.11

HEARTRATE
- MINE B HIGH
- MINE B AVG
+ MINE B LOW
☐ MINE A HIGH
☒ MINE A AVG
☐ MINE A LOW
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:

<table>
<thead>
<tr>
<th>Mine</th>
<th>Ton/mach/hour</th>
<th>Utilization</th>
<th>O/cost R/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>37.5 &amp; 35.6</td>
<td>87 &amp; 84</td>
<td>132,7 &amp; 87,4</td>
</tr>
<tr>
<td>B</td>
<td>14.7 &amp; 15.7</td>
<td>85 &amp; 82</td>
<td>150,8 &amp; 99,1</td>
</tr>
</tbody>
</table>

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 against 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/m² and they are exposed to a WBGT of between 29 and 34 °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 accumulative heat effect of the engine heat on the diesel powered vehicle operators.
TEMPERATURE ANALYSIS DRIVERS
WETBULB GLOBE TEMPERATURE -
DRIVERS AS PER NIOSH EXPOSURES LIMITS

WETBULB GLOBE TEMPERATURE °C

METABOLIC WORK RATE (W/m²)

VEH. TYPE & NIOSH LIMIT

- LHD TYPE 1
- LHD TYPE 2
- REL 30 min/h
- REL 45 min/h
- REL 60 min/h
- CEILING LIMIT

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

WE;TBULB GL.OBE TEMPERATURE C

60
50
40
30
20

METABOLIC WORK RATE W/m^2

VEH TYPE & NIOSH LIMIT

- DUMPTRUCK
- REL 45 min/h
- REL 60 min/h
- REL 30 min/h
- REL 60 min/h
- CEILING LIMIT

REL = RECOMMENDED EXPOSURE LIMIT
EXPRESSED IN WORK MINUTES / HOUR OF WORK PERMISSIBLE 80 FIG 2.13
R.E.F. REFERENCES

1. Heat load - Diesels


Patterson, A.M., Ventilation and refrigeration considerations in the design of a deep hot gold mine using trackless mining, JCI Internal publication, 1989.


REFERENCES

2. HEAT STRESS - OPERATORS


Roger W. Hubbard, Hyperthermia: new thoughts on an old problem, Physician Sportmedicine, vol. 17, no. 6, June 1989,


Belding H.S., Hatch T.F., Index for evaluating heat stress in terms of resulting physiological strains eating, piping and air conditioning, August 1955.


A training manual to be used for the selection and protection of individuals destined to perform physical work in hot environments COMRO, Industr. Hygiene Lab. 1986.


Numseley S.A., & Stribley R.F., Fighter index of thermal stress (fits) guidance for hot weather aircraft operations Aviation, Space & Environ. Medicine, June 1979, p 639.


Greenleaf J.E., etc., Fluid-electrolyte shifts and thermoregulation rest and work in heat with head cooling Aviation, Space & Environmental Medicine, 51 (8), August 1980.


Kielblock, J., Physical work rates of workers involved in Mechanised Mining, Private communication COMRO - WAGM, (01 Desember 1988) (p1)


Hancock, P.H., Heat Stress Impairment of mental performance. A Revision of tolerance limits Aviation, Space & Environmental Medicine, March 81, p 177.


Back-up documentation on LHD's into the '90's Tech. specs, International Mining, July 1990, p 17.

Vehicle specifications, JCI RJ TMMH WAGM, October '90.
NOTE:

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

PANEL SPEC: 0.5 m WIDE X 4.0 m LONG
0.05 m MAX. BACKFILL TO FACE
0.05 m/sec AIR SPEED ON PAGE

AIR REQUIREMENT: 0.15 m³ FACE ADV./MONTH (AND 2070042) PLUS 22% LEAKAGE IN 3.1 m³ PER YEAR AND AT 1.8 kg/m³ DENSITY

NARROW REEF STOPING ENVIRONMENTAL CONTROL STRATEGY
WESTERN AREAS GOLD MINING COMPANY LTD.
SOUTH DIVISION - ENVIRONMENT ENGINEERING.
83 TMM WORKSHOPS - ENVIRON. CONTROL.

LOADING BAY - TM & TRACKS
INSTALL 3X 'TM' DOORS
2X 2.6 T. DIESEL PLANT
20m³ S
VIA TIP RSE

LEGEND
- WORK BAY
- 760mm Ø JET FAN
- 570mm Ø EXTRACTOR FANS
- FIRE DOOR

83 TM³ SOUTH
600KW COOLTH
35m³ S
T = 18.6/10.6°C
(AFTER COOLING)

83 TM³ SOUTH
500KW COOLTH
40m³ S
T = 22.6/21.3°C
(AFTER COOLING)
TO MAJOR INTAKE & RAW'S IN WASTE

2.5 KW JET PANS POINTS [DISTANCE]

SAME ARREST ON BOTTOM CONDUIT

VERTICAL CENTER

MAIN ACCESS VS (REMOVAL)
TENP.AIR: 28.00 C 35.00

FILE NAME: VPER58L APPL

BAR(NESS: 100.15 kPa

Note: date: 1-9-90 (VEil

kW rated 144.00 kW

Power 133.60 (derated) AT

WESTERN AREAS GOLD MINING COMPANY LIMITED

MACHINE PERFORMANCE

PERIOD: MARCH 1989 - FEBRUARY 1990

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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.

86
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**Note:** Utilization is taken as total hours operating split over the three shifts on a ratio basis. Fuel consumption expressed at duration due to ambient conditions.
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Utilization is taken as total hours operating split over the three shifts on a ratio basis.

Fuel consumption expressed at derated due to ambient conditions.
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Note: The data represents fuel consumption and efficiency rates over a six-month period, from March 1988 to August 1988, for a machine performing work in different months, with shifts varying from one to three hours. The table includes columns for monthly hours operated, fuel consumption, and various efficiencies such as kWh/kW, kW/kW, and MWh/kW/H.
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**NOTES:**

- Not all vehicles have been evaluated.
- The following summary is necessary of the remainder of units.
### Table:schlieft Duration of Work

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**Note:**
- The table shows the shift duration effective at work for different names.
- The shift duration includes 1st, 2nd, and 3rd shifts.
- Overtime is calculated separately.
- Total shift duration includes all shifts and overtime.

---

**Other Information:***
- **File Name:** VERS4
- **Answer:**
  - **Date:** 1-9-99
  - **Shift Duration:**
    - 1st shift = morning shift = 6 hrs
    - 2nd shift = afternoon shift = 6 hrs
    - 3rd shift = evening shift = 6 hrs

---

**Company Information:**
- **Company Name:** Western Area Gold Mining Company Limited
- **Periods:** March 1990 - February 1991

---

**Additional Information:**
- **Overall Performance**
- **Fuel Consumption**

---

**Data:**
- **Temp:** 20.00°C
- **Humidity:** 35.00%
- **Machine:** Trackless Mechanized Mining Methods
- **Weight:** 144.00 tons
- **Power:** 133.00 kw (Draughted)

---

**Shift Details:**
- **1st Shift:**
  - 10:00 - 22:00
- **2nd Shift:**
  - 22:00 - 02:00
- **3rd Shift:**
  - 02:00 - 10:00

---

**Report Details:**
- **Date:** 1-9-99
- **Shifts:**
  - 1st shift = morning shift = 6 hrs
  - 2nd shift = afternoon shift = 6 hrs
  - 3rd shift = evening shift = 6 hrs

---

**Notes:**
- **Machine Efficiency:**
- **Fuel Consumption:**

---

**Other Information:**
- **Name:** John Doe
- **Position:** Operator
- **Date:** 1-9-99

---

**Conclusion:**
- The shift duration for each shift is effective at work.
- The total shift duration includes all shifts and overtime.

---

**Additional Notes:**
- **Company Name:** Western Area Gold Mining Company Limited
- **Periods:** March 1990 - February 1991
- **Overall Performance**
- **Fuel Consumption**

---

**Data:**
- **Temp:** 20.00°C
- **Humidity:** 35.00%
- **Machine:** Trackless Mechanized Mining Methods
- **Weight:** 144.00 tons
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<td>C</td>
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</table>

**Note:**

- Shift A: Morning shift = 0 hrs
- Shift B: Morning shift = 0 hrs
- Shift C: Morning shift = 0 hrs

**APPENDIX F**

- This section is dedicated to the research details and conclusions.
Appendix H

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

**Physiological**

1. Base-line heart rate (Hr)
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

**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 kanta) as check but primarily by volometer
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

**Influential Factors**

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

4. Temp./ wet and dry in Calculated :-

1. Sweat loss g/kg body weight

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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, characteristics at base line information.
   - Body mass, 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 1/min-1.
   - at ml/kg-1 min.
   - Mass index.
   - Temperature skin.

2. Influential 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.
Appendix H P3/15

- 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 negligible.
- 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 satisfactorily.
Appendix II P4/15

B. Output data

Heat balance = \( M - W - Q - S = R + C + E + G = \delta S \)

1. Heat stress after Kamon 5-16
   - Radiant heat transfer.
   - Convection heat.
   - Evaporation heat.
   - Influence of clothing.
   - Wetbulb globe temperature.
   - Sweat rate: Evaporation effectiveness (\( \text{req/eff} \))
     maximum (\( \text{req/max} \)).
   - 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.
   - Convective heat transfer.
   - Latent heat transfer.
   - Sweating efficiency.
   - Evaporative heat transfer.
   - Sweat rate.
   - Metabolic work rate as per baseline.
   - Respiratory heat exchange.
   - Water vapour pressure.
   - Metabolic workrate as per reference 5-28.
     and \( M = 343 \, Q_T \left( \frac{30.39 - q}{100} \right) \).
   also calculate CET, ET & Hb as comparator.
3. Heat balance equation after NIOSH 5-11
   Change in body heat content by evaluating:
   - Convective heat exchange.
   - Radiant heat exchange.
   - Evaporative heat exchange.
   - Maximum water vapour uptake capacity.

   this is necessary 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. Microclimate cooling effect on operators
   (initial study)

6. Comparison of the various indexes
Appendix H P6/15

Additional information on formulae used

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

\[ \text{W3} = \text{Wm}^2 = (\text{W1} + (\text{W2} - \text{W1})*((\text{HR3} - \text{HR1})/((\text{HR2} - \text{HR1}))))*\text{As} \]

Where \( \text{W3} \) = Required metabolic work rate
   \( \text{HR1} \) & \( \text{W1} \) = Condition 1 parameters
   \( \text{HR2} \) & \( \text{W2} \) = Condition 2 parameters
   \'As' is skin area = 0.217 m\(^2\) * 0.425 * Ht\(^0.725\)

2. Stepping height for baseline

\[ (\text{W} * 6000)/(9.81 * \text{SR} * \text{M}) \]

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

3. \( \text{Qr} = \text{Vo2} = \) Ventilation rate or \( \text{Q}_2 \) consumption

\[ = 0.52 + 0.0214 (\text{HR} - 70) \text{ in l/min} \]

4. \( \text{Qr max} = \text{Vo2 max} = 0.172 + 0.525 \text{ ffm in l/min} \)

Where \( \text{ffm} = \) fat free body mass

5. \( \text{Qr max} = \text{Vo2 capacity} = 0.52 + 0.0417 \text{ Bm} \)

Where \( \text{Bm} = \) Gross body mass

6. \( \text{W} \) at 145 b/min, assume straight line performance

based on equa 1 = 100 + (((145-H2)/(H2-H1))*W0H2-W0H1)
FORMULAE AFTER KAMON (1981:611)

1. \[ R = Fcl \cdot kr \cdot (Tr^4 - Tsk^4) \] See 4
   = RADIANT HEAT exchange
   Where:
   - \( Fcl \) is insl. value cloths correction =
     \( (1 + 0,85\times 0,8 \times lclo) \)
   - \( kr \) is coeff Temp - Energy Stefan Boltzmann const &
     emissivity for black body
   - \( Tr \) is mean radiant derived from \( Tg \) where:
     \( Tr^4 = Tg^4 + kg \times 0,5 \times (tg - tdb) \)
   Where: \( kg \) is coeff heat transfer between
   globe and air
   - \( Tg \) is abs.Temp of the globe
   - \( tsk = 273 + 36 = 309\)°k

2. \[ C = Fcl \times Kc \times V^{0.6} \times (tdb - tsk) \] See 5
   Where \( C \) = Convective Heat exchange
   - \( Kc \) is conv factor Temp to Energy
   - \( V \) is air movement
   - \( tdb \) is dry bulb
   - \( tsk \) mean skin Temp
   - \( Fcl \) is \( l(1 + 0,155\times 0,8\times 0,5\times lclo) \)

3. \[ Ereq = M \pm R \pm C \]
   = Evap. Required
   Where \( M \) is metabolic heat load \( W.m^{-2} \)

4. \[ R = Fcl \times 4,36\times 10^{-8} \times [(tr + 273)^4 - 9,117\times 10^{-9}] \]
   \( W.m^{-2} \)
   \[ tt = \sqrt[4]{(tg + 273)^4 + 2,47\times 10^{18} \times 0,5 \times (tg - tdb)} - 273 \ C \]

5. \[ C = Fcl \times 0,5 \times (tdb - 36) \ W.m^{-2} \]

6. \[ Emax = Fpcl \times Ke \times 0,5 \times (Psk - Pa) = \text{Envon.Cap. for Evap.} \]
   \( (\text{See 10}) \)
   \( Ke \) is conv press. to energy
   - \( Psk \) is vap.press skin & \( tsk = 44 \) mm HG
   - \( Pa \) is ambient vap press for \( tpwb \) & \( tdb \) (see 9)
Where NSI is heat stress index by Belding and Hatch

\[ W = \text{HSI/100} = \text{Erreq/Emax} \]

Where NSI is heat stress index by Belding and Hatch

\[ W = \text{degree of wetness due to sweating} \]

7. \( E_{LS} = \text{Sweat rate of 1 L.hr}^{-2} \)

8. \( E_{eff} = Sw*Zs*e^{-k*W} = 300*3.06*e^{-1.52W} \text{ in W.m}^{-2} \)

Where \( E_{eff} \) is evap. sweat in terms of energy transfer

\( Sw \) is sweating rate limited to 1 L." 

\( Zs \) is conversion factor from sweat to energy.

\( k \) is a regression constant.

9. \( Pa = (4.8e^{-0.0629*tpwb})0.0066*BP*(t_{db}-t_{pb}) [(1+0.00115)* \]

\( (t_{db}-t_{pb}) \] in mm HG

Where: \( t_{pb} \) is psychro. wetbulb

10. \( p_{cl} \) for \( E_{max} = 1(1 + 0.143*8.5*V^{0.6}*1cl0) \)

11. Conversion \( tpwb - tnwb \)

\( tpwb = tnwb - 0.5-0.13(tg-t_{db}) \) for \( V > 1 \text{ m.s}^{-1} \) in °C

\( tpwb = tnwb - 1.5-0.13(tg-t_{db}) \) for \( V < 1 \text{ m.s}^{-1} \) in °C

12. Time limit \( = 60 / (E_{req} \cdot E_{max}) \)

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HEAT STRESS INDEX FORMULAE
(After Stewart-1984:495)

1. Cooling Power Concept:
   (Where $D_{twb}$ to $t_{db} < 2\,^\circ C$
   
   $$ CP = f_r \cdot hr (ts - tr) + hr (ts - ta) \cdot he (ps - pa) $$

   Where:
   - $f_r$ = view factor for radiant heat exchange from human
   - $hr$ = radiant heat transfer coefficient $W/m^2 \cdot ^\circ C$
     $$ hr = 4.61 \left(1 + \frac{(tr+ts)}{546}\right)^{3/8} $$
   - $tr$ = Stefan Boltzman radiant coefficient
   - $ts$ = mean skin temperature measured or default @ 36.5\(^\circ\)C
   - $ta$ = ambient dry-bulb temperature, °C
   - $W$ = wet sk 1 fraction
   - $he$ = evap. heat transfer coefficient
     $$ he = 1587*hc*P/(P - ps)^1 $$
   - $pa$ = water vapour pressure in ambient air, kPa,
     $$ pa = P'ws - Ap (t_{db} - twb), kPa $$
   - $ps$ = saturated water vapour pressure at temp. $ts$, kPa

   Where:
   - $P'ws = 0.6105.exp(17.27 twb/(237.3 + twb))$, kPa
   - $A = 0.0064/\circ C$

   Notes
   - Respiratory 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 $CP \geq M$
   - $M$ is metabolic energy generation also called metabolic
     heat/O\(^3\) consumption
   - This equation is incorrect for elevated radiant temperatu-
     res and when the gap between $twb$ and $t_{db} > 2\,^\circ C$
     therefore use the next equation
Appendix H P10/15

2. Cooling power concept or Equivalent Cooling power
(Where \( \text{stwb} \) to \( \text{tmb} \) > 2°C)

\[
\text{CP} = \text{fr*hr} \times (\text{ts} - \text{tr}) + \text{hr} \times (\text{ts} - \text{ta}) + \lambda \times w \times \text{Sr} + Q
\]

Where: 
\( \text{fr}, \text{hr} \) and \( \text{hr} \) are as per equation 1
\( \lambda \times w \) = Efficiency of sweat as cooling mech. for partial wet person and sweat dripping up to \( \text{Emax} \)
\( \text{Emax} = E/\lambda \times \text{Sr} \) where: \( E = \text{As} \times \text{w} \times (\text{ps} - \text{pa}) \) and \( \text{w}, \text{he}, \text{ps} \) & \( \text{pa} \) is as per equation 1

Where: 
\( E = \) Evaporative heat transfer
\( \text{As} = \) Skin surface area, \( m^2 = 3.217 \times 10^{-10} \times 0.425 \times 0.725 \)
Where: 
\( \text{mt} = \) mass of human body, kg
\( \text{Ht} = \) height of person, m
\( \lambda = \) latent heat of vaporization of sweat, kJ/kg
\( = 2501 - 2.387 \times \text{twb} \)
\( \text{Sr} = \) Sweat rate, kg/m²s~\( T_E \) and
\( T_E = (0.1 \times \text{ts} + 0.9 \times \text{tr}) \) using \( T_E \) read off sweat rate from
\( \text{Sr} = \) Sweat rate, kg/m²s and ~\( T_E \)

Where: 
\( T = \) Thermoregulatory signal °C
\( \text{Sr} = 36-37°C \) then \( \text{Sr} = (0.321/60) \times T_E - 36 \)
\( = 37.1-38°C \) then \( \text{Sr} = 0.321 + (0.785/60) \times T_E - 37.1 \)
\( = 38.1-39°C \) then \( \text{Sr} = 1.106 + (0.295/60) \times T_E - 38.1 \)
\( \text{Emax} = \text{As} \times 965 \times (p_i^{1.6}/(p - \text{pa}))^{0.8} \times (\text{ps} - \text{pa}) \)

Where: 
\( P = \) Atmospheric pressure, kPa

and
\( Q = \) Respiratory heat exchange
\( = 1.7 \times 10^6 \times M \times \text{cp} \) (\( \text{two} - \text{tw} \))

Where: 
\( M = \) Metabolic energy production = \( W \times \text{As} \)
\( \text{Cp} = \) Specific heat of moist air = 6000 J/kg °C
\( \text{two} = 32.6 + 0.066 \times \text{ta} + 0.20 \times \text{pa} \)

Notes:
- Applies to any condition found underground, especially in THM³ projects where \( \text{tr} \) > \( \text{tmb} \) > \( \text{twb} \)
- Ratios of \( V_02 \max \sim M \sim \) heart rate is shown in equation 3
3. **Metabolic Energy (M)**

\[ M = 343 \times Q_r \times \frac{(20.39 - e)}{100} \]

Where:
- \( Q_r \) = Respiratory flow rate (l/min)
- \( e \) = % \( \text{O}_2 \) in exhaled air
- 343 = constant
- 20.39 = % \( \text{O}_2 \) in atmosphere by volume
- \((20.39 - e)\) = \( \text{O}_2 \) consumption

**Note:** Muscles may be \( \leq \) 20% max when performing heavy physical work.

Now Prediction of \( \text{VO}_2 \) from parameters: age, body mass, body height, relative fat, heart rates at various sub-max work loads and max Heart Rate

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

i. \( Q_r = \text{VO}_2 \) in l/min = 0.52 + 0.0214(\( \text{hr} - 70 \))

ii. \( Q_r = \text{VO}_2 \) max in l/min = 0.172 + 0.525 FFM

Where:
- FFM = fat free body mass in kg

iii. \( Q_r = \text{VO}_2 \) capacity in l/min = 0.55 + 0.0417 BM

Where:
- BM = Cross body mass in kg

4. **Radiant Temperature** (using black globe)

\[ T_r = \left[ \frac{(T_g + 273)^4}{1.1 \times 10^8 \times (0.95 + 0.4)} \left( \frac{T_g - T_a}{0.25 - 273} \right) \right] \]

Where:
- \( D \) = \( \phi \) globe (m)
- \( T_a = T_{\text{db}} \)
Appendix H P12/15

6. Heat balance equation
   \[ M = As_{fr \ hr} (ts-tr) + As_{hc} (ts-ta) + As*e*he (ps-pa) \]
   Where: all factors are as previously mentioned and as per 'CP' equation. \( As \) is skin area.

7. Cooling power values for safe heat exposure
   'CP $10^{-6}$' = \( R + C + E_{\text{max}} \)
   \[ R = 4,93 \ As (ts-tr) = \text{Radiant heat exchange} \]
   \[ C = 0,608 \ p^{0,6} \ v^{0,6} (ts-ta) \]
   \[ E_{\text{max}} = 965 \ (p^{1,6} / (p-pa)^2) \ v^{0,6} (ps-pa) \]
   Where \( ts \) is taken for a $10^{-6}$ change of heat stroke i.e. \( ts \geq 40^\circ C \) conditions.
   and
   \[ ts \text{ for } W/m^2 \ 100 \text{ to } 240 = \left[ \frac{35,8 - (35,8-34,6) \times (240-M)}{240} \right] \]
   \[ = 35,8 - 0,005 \ (240-M) \]
   \[ ts \text{ for } W/m^2 \ 240 \text{ to } 300 = \left[ \frac{34,6 - (34,6-33,2) \times (300-M)}{300} \right] \]
   \[ = 34,6 - 0,0047 \ (300-M) \]

8. Thermal comfort (as TC) for unacclimatized people
   in TC, \( ts = 35,7 - 0,032 \ (M-W) / As = \text{Skin temperature} \)
   and \( E = 0,42 \ ((M-W)-58) = \text{Evaporative cooling (Sweat rate)} \)

9. Relative Humidity
   \[ o = (Pa/P'ws) \times 100\% \]
   and \( Pa = P'ws - AP(tdb-tw) \)
   \( P'ws = \text{Saturated vapour press } @ \text{twb kPa} \)
   \[ = 0,6105 \exp (17,27 \text{ twb} / (237,3 \text{ twb}) \text{ kPa} \]
   \( \ell = 0,000644^\circ C \)
   \( = \text{Bar pressure in kPa} \)

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Appendix H P13/15

\[ P_{\text{wss}} = 0.6105 \exp \left( \frac{17.27 \, \text{tdb}}{237.3 + \text{tdb}} \right) \, \text{kPa} \]

**Remarks**

Equations 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.
\[ \text{Heat balance equation (USD of H & H Services, 1986)} \]
\[ (\text{NIOSH 86 - 113}) \quad (5 - 7) \]

Where \( \Delta S \) = Change in body heat content
\[ M-W = \text{Total metabolism - external work performed} \]
\( C = \text{Convective heat exchange} \)
\( R = \text{Radiant} \)
\( E = \text{Evaporative} \)

1. \[ C = hc(\text{ta}-\text{tsk}) = \text{Corrective heat exchange} \]

Where:
\[ hc = 2.35 \ (\text{tsk-\text{ta}})^{0.25} \] at very low airspeeds
\[ = 3.5 + 5.2 \ \text{Var} \quad \text{where Var is relative airspeed} \]
\[ < 1 \text{m/s} \]
\[ = 8.7 \ \text{Var}^{0.6} \quad \text{where Var is} \ > 1 \text{m/s}^{-1} \]
and \( \text{Var} = Va + 0.0052 \ (\text{N=58}) \) if movement is due to muscles activity

Or
Simply add 0.7m/s\(^{-1}\) if muscular only

Sensible heat exchange due to clothes (Fcl)

\[ Fcl = 1/(1 = (hc + hr)) \]

Where \( Fcl \) is the thermal insulation for clothes

also
\[ C = hc Fcl (\text{tsk}-36) \text{ in Wm}^{-2} \]

and
\[ Fcl = (0.8(0.06 + 0.09 + 0.26 + 0.4 + 0.48) + \begin{array}{c}
\text{Underwear} \\
\text{Trousers} \\
\text{Socks} \\
\text{Boots} \\
\text{Tshirt} \\
\text{Pants}
\end{array} \]

2. \[ R = hr Fcl (\text{tr-\text{tsk}})^{4} = \text{Radiant heat exchange in Wm}^{-2}/c \]

Where \( hr \) is coefficient of radiant heat exchange
\[ = 4 \ \text{Esk} \times (\text{Ar/Ado}) \left[ (\text{tr-\text{tsk}}) / 2 + 273 \right]^{3} \]
\[ = 5.67 \times 10^{-8} \ \text{Wm}^{2}/c^{4} \]
and \( \text{Ar}/\text{Ado} \) is the effect of body position on emissivity

Where \( \text{Ar} \) is area exposed to radiation

\[
\text{Adv} = \text{Du Bois' formulae in } \text{m}^2
\]

\[= 0.00718 \times \text{Weight} \div \text{Height}^{0.725}\]

and \( \text{W} \) is in \( \text{kg} \) and \( \text{H} \) in cm

and \( \text{Ar}/\text{Adv} = 0.77 \) Standing

\[= 0.70 \) Seated

\[= 0.67 \) Crouched

\( \text{tr} = \text{tg} \div 1.8 \text{ Va}^{0.5} (\text{tg}-\text{ta}) \)

\( \text{tsk} = 36^\circ \text{C} \)

3. \( E_{\text{max}} = (\text{psk}_s - \text{Ps}) / \text{Re} = \text{Evaporative heat exchange} \)

Where \( E_{\text{max}} \) is max water vapour uptake capacity \( \text{W/m}^2 \)

\( \text{psk}_s \) is Sat \( \text{H}_2\text{O} \) vapour press at \( 36^\circ \text{C} \) ts = 5.9 kPa

\( \text{pa} \) is partial \( \text{H}_2\text{O} \) vapour press at \( \text{ta} \) in kPa

\( \text{Re} \) is evaporation resistance of air and clothes

\[= 1 / (16.7) / (\text{hc}) / \text{Fpol} \]

Where \( \text{Fpol} \) is reduction factor for loss in latent heat exchange due to clo

\[= 1 / (1 + 0.92 \text{ hc}) / \text{tcl} \]

Sweat rate default = 650 gms/hour for 8 hours

acclimatised

\[= 400 \text{ gms/hour for 8 hours} \]

unacclimatised person

\( S_{\text{req}} = E_{\text{req}} \)

Where \( S_{\text{req}} \) is Required sweat (\( \text{W/m}^2 \)) also in gms/hr/m\(^2\)

\[\text{W/m}^2 = (\text{gms/hr/m}^2) \times 0.63\]

\( W = E_{\text{req}}/E_{\text{max}} \) is wettedness factor

\( E_{\text{req}} \) is Required evaporation = \( M + C + R \)

Evap Eff of nude person = \( 1 - 0.5/\text{c} - 6.6(1-\text{W}) \)

\( \text{c} \) is base of natural logarithm
## HEAT STRESS ANALYSIS OF DIESEL POWERED VEHICLE OPERATORS

### BASELINE INFORMATION

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### APPENDIX 1

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HEAT STRESS ANALYSIS OF DIESEL POWERED VEHICLE OPERATORS

APPENDIX I

LOCALITY: IND TM3
BAR PRESS: 106 kPa
DATE: 07/12/90

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

HEART PROFILE

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110
### Heat Stress Analysis of Diesel Powered Vehicle Operators

**Input Parameters**

- **Person:** Lucky
- **ID Number:** 1421670
- **Type of Machine:** LHD
- **Vehicle:** 32 Body Mass: 66.0 Height: 1.7 Skin Area: 1.02 M
- **Heart Profile:**
  - 54 N 90 b/min
  - 70 N 104 b/min

**Environmental Parameters**

- **Wind Speed:** 5.02
- **Wind Chill:** 0.02
- **Wind Chill:** 0.02

**Heat Rate/Heat Temp:**

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<th>Airspeed</th>
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**Conditions**

- **Wind Speed:** 5.02
- **Wind Chill:** 0.02
- **Wind Chill:** 0.02

**Heat Rate/Heat Temp:**

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**Heat Rate/Heat Temp:**

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**Heat Rate/Heat Temp:**

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### BASIC INPUT DATA, METABOLIC WORK RATE & PSYCHOMETRIC DATA

#### METABOLIC HEAT PRODUCTION & PSYCHOMETRIC DATA

- **Qr** = **Qr** : **T**E**M**P. **H**L **M** = **Pa** = **Pa** = **H**L **T**r = **H**L
- **b/m** = **W**2 **B**N = **W**2 **H**L: **s**: **p**e**r** **t**e**m** **P**r**r** = **W**/**m**2: **b**/m = **m**/**m**2: **H** = **C** = **W**/**m**2

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### Notes
- The table contains various measurements and calculations related to metabolic heat production and psychometric data, including temperature, pressure, and work rates.
- Each row represents a different set of values for these parameters.
- The units for each measurement are indicated in the top row of the table.
### BASIC INPUT DATA, METABOLIC WORK RATE AND PSYCHOMETRIC DATA

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<th><strong>OXYGEN CONSUMPTION</strong></th>
<th><strong>METABOLIC DATA</strong></th>
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<td>W/m²:</td>
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### Basic Input Data, Metabolic Work Rate and Psychrometric Data

#### Metabolic Heat Production

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<th>m</th>
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<td>V02 HR</td>
<td>per input</td>
<td>W/m²</td>
<td>kPa</td>
<td>g/HG</td>
<td>°C</td>
<td>W/K</td>
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| **** | 123 | 3.06 | 11.06 | 208 | 193.19 | 4.06 | 0.76 | 75.52 | 30.00 | 261.70 |
| **** | 123 | 3.06 | 13.79 | 206 | 224.70 | 4.08 | 0.74 | 75.57 | 30.05 | 258.26 |
| **** | 123 | 3.06 | 13.79 | 206 | 224.70 | 4.08 | 0.74 | 75.57 | 30.05 | 258.26 |
| **** | 123 | 3.06 | 13.79 | 210 | 224.70 | 4.08 | 0.74 | 75.57 | 30.11 | 259.79 |
| **** | 123 | 3.06 | 13.79 | 212 | 224.70 | 4.04 | 0.73 | 75.63 | 30.06 | 249.30 |
| **** | 123 | 3.06 | 13.79 | 216 | 224.70 | 4.08 | 0.72 | 75.66 | 30.06 | 249.30 |
| **** | 119 | 3.06 | 11.01 | 216 | 175.19 | 4.08 | 0.73 | 75.63 | 30.03 | 249.30 |
| **** | 119 | 3.06 | 11.01 | 210 | 175.19 | 4.08 | 1.06 | 71.48 | 30.06 | 249.30 |
| **** | 119 | 3.05 | 11.01 | 220 | 179.18 | 4.02 | 0.94 | 72.05 | 30.11 | 249.30 |
| **** | 119 | 3.05 | 11.01 | 220 | 179.18 | 4.06 | 0.84 | 74.24 | 30.17 | 249.30 |
| **** | 119 | 3.05 | 11.01 | 220 | 179.18 | 4.04 | 0.83 | 74.76 | 30.08 | 249.30 |
| **** | 124 | 3.06 | 12.09 | 220 | 256.80 | 4.03 | 0.79 | 75.51 | 30.46 | 249.06 |

### Psychrometric Data

#### Count

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</tr>
</thead>
</table>

### AVG

| AVG | 3.06 | 5.25 | 113.00 | 64.80 | 3.41 | 1.47 | 69.50 | 34.02 | 180.97 |

### MAX

| MAX | 3.06 | 13.79 | 225.50 | 224.79 | 4.27 | 5.55 | 83.70 | 41.54 | 259.38 |

### STD

| STD | 4.45 | 65.12 | 72.78 | 0.44 | 4.39 | 6.97 | 3.79 | 46.04 |

### VAR

| VAR | 0.00 | 17.78 | 4331.67 | 5296.42 | 7.19 | 5.70 | 68.56 | 14.35 | 1685.11 |

<p>| 114 |</p>
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**Figure 1.** Distribution of body temperature (°C) in normal human subjects.
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**Notes:**
- **Count:** Number of observations.
- **Min:** Minimum value.
- **Max:** Maximum value.
- **Ave:** Average value.
- **Std:** Standard deviation.
- **Vr:** Variance.
- **Time:** Time of measurement.
- **Temp:** Temperature.
- **Rpm:** Rpm of the engine.
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APPENDIX K

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% of the 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 formulas 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:

\[ q_r = 5.67 \left( \frac{T_1}{100} \right)^4 - \left( \frac{T_2}{100} \right)^4 A_2 F_{ev} \]

where:
- \( q_r \) is the radiant heat ex the engine in W/m².
- \( T_1 \) 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 Boltzmann constant for radiant heat transfer
- \( A_2 \) is the total area of the cabin wall in m²
- \( F_{ev} \) is emissivity or view factor in terms of \( T_2 \)

and:

\[ T_2 = \frac{1}{\varepsilon_1 + (A_1/A_2(1/\varepsilon_2 - 1))} \]

where:
- \( \varepsilon \) is the view factor of the heat transfer plane

and:

\[ q_{c1} = h_c A (T_{wall} - T_{cabin}) \text{ in W/m}^2 \]

where:
- \( h_c \) is the convective heat transfer coeff and is dependant on the ambient conditions in the cabin in terms of temperature and airflow.

Also \( h_c = 5680 (1+0.015t)^{0.8}/d^{0.2} \) with airflow in the cabin or

\[ h_c = 1.4 (T_{wall} - T_{cabin})^{1/3} \]

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 \( t_{\text{wall}} \).

where:
\[
\text{LMTD} = \frac{(t_{A_2} - t_{A_3})}{\log_e(t_{A_2}/t_{A_3})}
\]

and : \( t_{A_2} \) is the average temperature of the steel subtratt also called the cabin wall, on the engine side of the cabin in ° kelvin.
\( t_{A_3} \) is the average temperature of the steel subtratt also called the drivers cabin, on the ambient air side of the cabin in ° kelvin.

and:
\( q_{c_2} \) is the conductive heat transfer

\[
q_{c_2} = 2 \cdot k \cdot T \cdot (t_{ae} - t_{ac})
\]

where:
\( k \) is the thermal conductivity of the steel subtratt @ 45.0 W/m² (neglecting the paintwork on the steel)
\( T \) is the temperature of the steel in kelvin
\( t_{ae} \) is the engine compartment air temperature in ° kelvin.
\( t_{ac} \) is the air temperature in the cabin in ° kelvin.
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.