Analysis of heat sources: Alternatives for improving environmental conditions in an underground gold mine

Análise das fontes de calor: Alternativas de melhorias das condições ambientais em uma mina subterrânea de ouro

Análisis de fuentes de calor: Alternativas para mejorar las condiciones ambientales en una mina de oro subterránea

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Abstract
Heat generation in underground mines is a factor of extreme influence on the production, safety and comfort of workers. This article aims to analyze heat sources in an underground mine and propose, as one of the alternatives to improve ventilation conditions, replace the diesel fleet with electric. The case study shows that this is the second source of heat, being the first autocompression, the second diesel equipment and the third are the fans. The heat emitted by the rock then stabilizes a certain time having no significance in the temperature in the year of 2019, but in 2026 it will be a significant heat source. This evaluation was carried out in a gold mine near Belo Horizonte, capital of the State of Minas Gerais using the software Ventsim. In the study, sensitive heat and latent heat would be reduced by about 56% and 80%, respectively, if the change is made. This reduction in the heat generated by the system may improve working conditions because of lower temperature and gas concentration, which reflect on the safety conditions for higher worker's efficiency.
Keywords: Mine ventilation; Health and safety; Efficiency; Heat generated; Mining equipment.

Resumo
A geração de calor em minas subterrâneas é um fator de extrema influência na produção, segurança e conforto dos trabalhadores. Este artigo tem como objetivo analisar fontes de calor em uma mina subterrânea e propor, como uma das alternativas para melhorar as condições de ventilação, substituir a frota a diesel por elétrica. O estudo de caso mostra que esta é a segunda fonte de calor, sendo a primeira a autocompressão, a segunda os equipamentos a diesel e a terceira são os ventiladores. O calor emitido pela rocha então se estabiliza por um certo tempo não tendo significância na temperatura no ano de 2019, mas em 2026 será uma fonte de calor significativa. Esta avaliação foi realizada em uma mina de ouro próxima a Belo Horizonte, capital do Estado de Minas Gerais, utilizando o software Ventsim. No estudo, o calor sensível e o calor latente seriam reduzidos em cerca de 56% e 80%, respectivamente, se a alteração fosse feita. Essa redução do calor gerado pelo sistema pode melhorar as condições de trabalho devido à menor temperatura e concentração de gases, o que reflete nas condições de segurança para maior rendimento do trabalhador.
Palavras-chave: Ventilação de mina; Saúde e segurança; Eficiência; Calor gerado; Equipamentos de mineração.

Resumen
La generación de calor en las minas subterráneas es un factor de extrema influencia en la producción, seguridad y comodidad de los trabajadores. Este artículo tiene como objetivo analizar las fuentes de calor en una mina subterránea y proponer, como una de las alternativas para mejorar las condiciones de ventilación, sustituir el parque de motores diesel por eléctrico. El estudio de caso muestra que esta es la segunda fuente de calor, siendo la primera la autocompresión, la segunda los equipos diésel y la tercera son los ventiladores. El calor emitido por la roca luego se estabiliza en un cierto tiempo sin tener importancia en la temperatura en el año de 2019, pero en 2026 será una fuente de calor importante. Esta evaluación se realizó en una mina de oro cerca de Belo Horizonte, capital del Estado de Minas Gerais, utilizando el software Ventsim. En el estudio, el calor sensible y el calor latente se reducirían en aproximadamente un 56 % y un 80 %, respectivamente, si se realiza el cambio. Esta reducción en el calor generado por

el sistema puede mejorar las condiciones de trabajo debido a la menor temperatura y concentración de gases, lo que se refleja en las condiciones de seguridad para una mayor eficiencia del trabajador.
Palabras clave: Ventilación de mina; Salud y seguridad; Eficiencia; Generación de calor; Equipos mineros.

1. Introduction

The study of heat flow in the underground mine is very important for precise design ventilation. The insertion of diesel equipments was one of the biggest impacts of the last 100 years (Kocsis et al., 2009). In addition to the emission of pollutants, which can compromise air quality and employee health, these equipments contribute significantly to the increase in temperature. This problem tends to worsen with the deepening of mines and with the increase in production.

Anderson & De Souza (2017) report studies carried out in a potash mine, located in Canada. The application of appropriate procedures and controls of work practices will have a direct impact on the health and safety of workers and increase productivity. Using continuous monitoring stations, it was possible to monitor the environmental conditions and outline various strategies for the control of heat management.

Reducing heat flow in these cases is generally focused on installing refrigeration plants, which are expensive, or improving their efficiency. This article proposes as a possible alternative the change the form of energy that moves the equipment. Diesel machines are an overall efficiency of about a third of electric machines. In this way, fuel use will produce approximately three times as hot than electrical equipment (McPherson, 2009). In addition, the combustion process generates harmful pollutants that must be controlled in accordance with specific legislation (NR-17). In addition to artificial heat sources, there are other important factors that affect the temperature of underground air; for example, the external climate, the geological factors of the mine and mining method (Xiaojie et al., 2011).

Gyamfi et al. (2022) shows a study that was carried out to determine whether using ventilation on demand (VOD) could avoid this fan upgrade and reduce Konsuln's ventilation and heating power costs in the future. The study analyzed the possibility of using battery-powered equipment with the help of the demand ventilation technique (VOD) or other types of strategies that could lower these energy costs and heat emissions. The reduction in the circulation of gases emitted by diesel equipment, due to the use of electric ones, reduces the temperature in the mine and allows for a reduction in expenses with heat control.

To ensure the best environmental conditions the amount of air can be quantified using thermodynamic calculations or using one of the methods based on the density difference. The accuracy of these calculations depends on correctly determining air temperatures, pressures and humidity. Because of the magnitude and direction of the airflow the system in the mine is affected by seasonal temperature changes (Hartman et al., 1997).

In the surface cover of 15 m or 20 m to 30 m deep, the temperature of a rock varies throughout the year (Hartman et al., 1997). Below this surface, thermal, relatively neutral cover, the temperature of the soft rocky gradually increases depending on the increase in depth. This geothermal gradient can range from 10°C/km to 60°C/km depending on the geomorphological, geotechnical, petrographic and structural environment of the rock (Hall, 1981).

The mine under study has a geothermal degree of 1.4 °C/m and a current depth of 400 m. The aquifer lining of the mine is located in the northeastern portion of the Iron Quadrilateral. This range corresponds to the aquifer lining of about 16 km in length, which is composed of the alignment of fourteen mining excavations and two geochemical anomalies of gold, along trend NE-SW (Lima, 2012). It encompasses rocks of Archean and Proterozoic ages that have been tectonized by various folding, shear and failure events. Intrusive metabasic rocks and Cenozoic toppings also occur. He is in tectonic contact with the Rio das Velhas Sg. and the Coin Formation (Minas Sg.), through the system of push failures called Hot Water (Dorr, 1969). It occurs in an extensive range extending to both east and south-southeast. It is represented by gneisses and migmatites of tonalytic, granodioritic and granitic composition consisting essentially of quartz, plagioclasium, biotite, potassium feldspar and secondary carbonate.

They are cut by various gabrous/diabarous intrusions.

Future projections indicate that in 2026, to meet production targets the diesel fleet will be double and the mine will reach critical temperatures also influenced by increased depth. Therefore, the study of the main sources of heat and control measures are of great importance to maintain the environment in satisfactory conditions for human labor.

This article proposes to show the calculation of the heat of each specific source, in addition to comparing the results obtained in an underground mine using Ventsim software and empirical equations.

2. Methodology

There are several indexes that are used to define the thermal conditions of the underground environment. One of the oldest and simplest heat determinations is the dry bulb temperature. This index provides a reasonable assessment of heat conditions in a relatively dry mine atmosphere and successfully used in potassium mines to assess thermal conditions and set acceptable heat tolerance limits. The temperature of dry bulb alone is not suitable for evaluating the environment in hot or humid, since it does not provide any relative humidity measurement of the air. In addition to these data, barometric pressure, virgin rock temperature, geothermal gradient, rock type, moisture rate of galleries and shafts, diffusivity, thermal conductivity of the rock and specific heat) were collected between 2016 and 2019 or translation when in situ measurement for simulations with the software was not possible. The first step was to determine the behavior of airflow using Ventsim 5.0. This initial result was used to know the air conditions and heat sources (equipment, fans, blasted rock and heat emanating by rock).

To calculate the diffusivity and thermal conductivity, samples of rocks from the mine were collected and sent to the laboratory of the Federal University of Bahia for laboratory tests. The temperature of the rock was entered in the field. With these data it is possible to calculate the geothermal gradient which allows estimating the temperature of the mine at a given depth. This information is entered into the Ventsim software to carry out heat flow simulations in the mine. In this way the most critical areas of heat are determined. Therefore, it was developed a quantitative research methodology as described by Pereira et al. (2018).

The models were created from information obtained from real environments, after systematic data collection and identification of environmental parameters, with the purpose of characterizing the representative of the physical and operational environment to be modeled. Objectively, the resulting analyses seek significant improvements in the projects and operation of ventilation systems, concomitantly with reduced operating costs and improvement of the quality of the work environment in the mine studied.

A survey was conducted to determine the air characteristics throughout the mine. Air pressure, leakage, flow and air temperature were measured at strategic points of the ventilation network. In addition, the locations of fans, regulators and doors were defined. Ventilation networks can be solved using analytical methods or numerical methods. Analytical methods are based on mathematical models that provide exact solutions. On the other hand, numerical methods are an approximation. Before future planning simulations, the simulation of the current ventilation system correlated with reality, with an acceptable maximum of 5% divergence. Heat control was managed with climate simulations, as stated by Tuck (2008). An increase in airflow resistance during mine life was considered, planning an extra capacity of the ventilation system.

2.1 Rock heat

The mining method, the characteristics of the rock, depth and length of the galleries will influence the heat emissions of the strata. However, the amount of heat transmitted decreases over time. Sometimes, they can be obtained using empirical equations or methods used in similar mines (Mcpherson, 2009). The rate at which energy is transferred from rock to air is a function of the temperature difference between the rock surface and the air mass, surface roughness, air speed, percentage of wet rock surface and ventilation vapor pressure. Rock temperature is a function of thermal gradient, rock diffusivity and exposure time (Hall, 1981).

In the case study, data regarding rock were obtained in the laboratory and inserted in the software for the simulations. After the samples were determined, 3.70 W/°C and 2.27 W/°C for conductivity were determined, respectively. However, this information could be obtained if the data is not obtained, for gallery with more than 30 days of opening equation 1, described by Whilier (1987).

$$Q = 3.35.\ K.\ L.^{\ 0.854}.\ (VRT - \Theta d) \quad (1)$$

In which: q is heat flow of the rocky stratum (W); L is gallery length (m); K is the thermal conductivity of the rock (W/m°C); VRT is the temperature of virgin rock (°C); The average temperature of dry bulb (°C) is the average temperature of the dry bulb (°C).

Heat transfer can be from strata to air or air to strata, depending on which source presents the largest of them. This flow continues until there is thermal balance. When the galleries have been open for a long time, a phenomenon of thermal flywheel can arise, transferring heat from the air to the strata during the day and the opposite at night (Stroh, 1979).

The average temperatures of dry and humid bulb in the mine are 26° C and 21 °C, respectively. From this data it is possible to calculate the effective temperature according to NR 15 described by the equation 2.

$$IBUTG = 0.7*tw + 0.3*tu \quad (2)$$

In general, any environment or circumstance that exposes the body to heat sources greater than 35ºC can cause physical and mental changes of the worker. NR 15 establishes temperature tolerance limits through the Globe Thermometer Humid Bulb Index (IBUTG), described by the equations 3 and 4.

Internal environments external or no solar loader: IBUTG s 0.7 tbn + 0.3 tg (3)

External environments with solar charge: IBUTG s 0.7 tbn + 0.1 tbs + 0.2 tg (4)

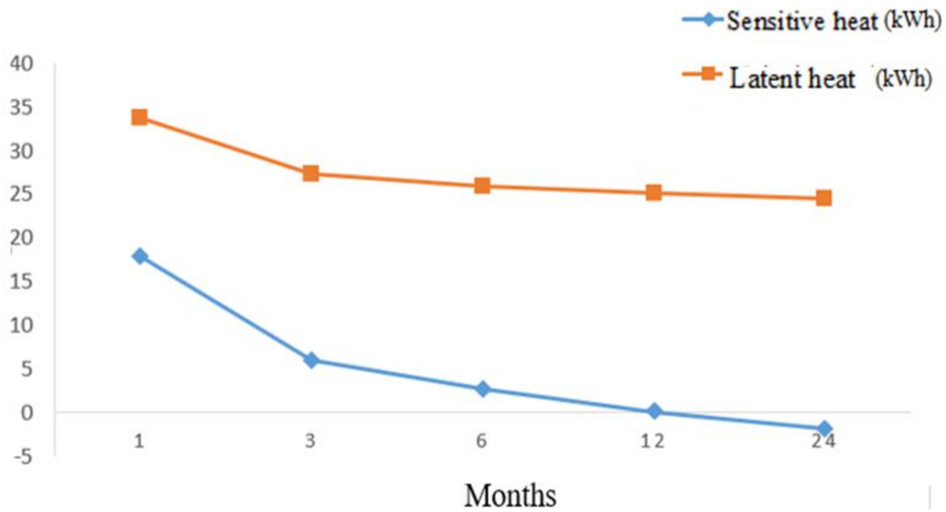
In which: tbn = natural wet bulb temperature; tg = globe temperature; tbs = dry bulb temperature. If the measured indices are high, NR-15 establishes criteria for intermittent working regimes according to Table 1.

Table 1 - Working regime depending on globe temperature.

Intermittent working with rest in the workplace itself	Activity type		
	Light	Moderate	Heavy
Continuous work	Up to 30°C	Up to 26.7 °C	Up to 25.0 °C
45 minutes work x 15 minutes rest	30.1 to 30.6°C	26.8 to 28.0°C	25.1 to 25.9°C
30 minutes work x 30 minutes rest	30.7 to 31.4°C	28.1 to 29.4 °C	26.0 to 27.9°C
15 minutes work x 45 minutes rest	31.5 to 32.2°C	29.5 to 31.1°C	28.0 to 30.0 °C
Work is not allowed without the adoption of appropriate control measures	>32.2 °C	> 31.1°C	> 30°C

Source: NR-15 Table 1.

Figure 1 – Behavior of stratum heat, whether sensitive or latent.



Source: Bacompta et al. (2016).

The results show that, over time, the transfer of sensitive heat from rock to the atmosphere tends to near zero after about a year, according to Bascompta et al. (2016) according to Figure 1.

2.2 Virgin rock temperature

The temperature of the virgin rock increases with the depth. The change in temperature is the result of the heat flow from inside the Earth, which is reasonably constant at about 0.05 W/m², although considerable variations occur. The temperature of the royal virgin rock (tvr) will depend on the thermal properties of the rock, the temperature of the rock near the surface, where it is reasonably constant and not influenced by surface temperature changes, and the temperature gradient, Δt demonstrated in equation 5.

$$T_{vr} = t_s + \Delta t. (D - d_s) \quad (5)$$

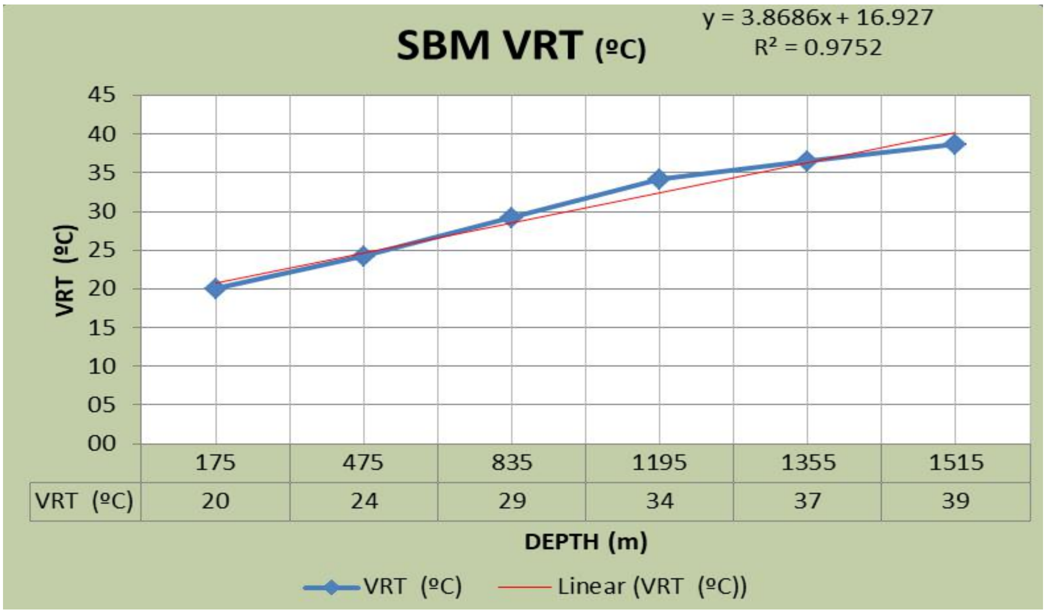
In which: T_{vr} is virgin rock temperature at depth D (°C); t_s is temperature at depth ds (°C); Δt is geothermal gradient (° C/m); d_s is depth below the surface where ts is measured (m).

The increase in rock temperature for every 100 m depth ranges from 1° to approximately 10 °C. In addition to regional differences, there may also be local variations in the temperature of the virgin rock (Voss, 1981).

Jones (2018) reports that in the gold mines in South Africa (4 km deep) a very extensive database of rock temperature measurements is available. Author presents profiles of 31 holes in the Bushveld Complex, which includes the Northam Mine, where refrigeration was implemented. Data were collected between 1985 and 2005, showing a constant range of 20.7 ± 1.3 K/ km. The geothermal heat flow, calculated from data and conductivity, is quite uniform at 45 ± 4 mW/m^2; in these measurements at the bottom of the holes, the highest temperature of virgin rock reached 70°C, in 2.2 km of depth.

Temperature change is determined by the coefficients of thermal expansion and difference of temperatures between strained and strainless states. From Figure 2 it is possible to estimate the temperature of the virgin rock at a certain depth of the case study mine.

Figure 2 – Temperature change in relation to the depth of the mine in geothermal gradiente study.



Source: Authors.

2.3 Electrical and diesel equipment

The mining method influences also in the generation of heat emitted in the ventilation system. The sublevel stoping method, used in the mine under study, allows the intensive use of mechanization and multiple fronts working, occasionally will require more airflow. The main heat source is the fleet of diesel equipment. Replacement by electrical or hybrid equipment is an alternative to this problem. The diesel machine produces both sensitive and latent heat. Electrical equipment produces only sensitive heat. The three main heat sources are: 1) radiator and machine body, 2) gas combustion, and 3) friction for machine use. For quantification can be considered a rate of 0,3 liters of diesel per 1kWh, with calorific coefficient of 34. 000 kJ/l (in Brazil this value is 43. 000 kJ/l) and a heat generation of 2.83 kWh for each kilowatt.

2.4 Equipment used in the mine

Tables 2 and 3 presents the quantity, power, liters/h consumption and model of diesel-powered equipment in addition to the same information for electrical equipment in a hypothetical change.

Table 2 – Characteristics of diesel equipment.

Type	Amount	Power (CV)	Power (kW)	Consumption (l/h)
Truck	3	408	304,25	34
Truck	7	350	261	34
Loader	5	268	199	15,1
Jumbo	4	90	66	6,5
Auxiliary Equipment	6	88	65	6

Source: Costa (2019).

Table 3 – Characteristics of electrical equipment.

Type	Amount	Power (CV)	Power (kW)
Truck	3	316	240
Truck	7	264	200
Loader	5	150	112
Jumbo	4	90	67,5
Auxiliary equipment	6	88	65

Source: Costa (2019).

Electric trucks and loaders are very similar in capacity and power. The models used are Caterpillar R 1600E and Scooptram EST1030/ Sandvik LHD154E for diesel and electric loader, respectively and Caterpillar AD 30 and / Atlas Copco/EMT35 for trucks.

The auxiliary diesel engine is relatively small compared to the main electric motors (72 kW vs. 2x200 kW in EMT-35) and the ventilation needs for this truck are much lower than for conventional vehicles using diesel engines. EMT-35 requires only about 17% of the air indispensable to dilute and evacuate gases emitted by similar 50 t diesel truck (Paraszczak, 2014). Another option suggested by Lafuente (2017) would be the application of hybrid equipment. The drive system features a diesel engine and four electric motors. Compared with diesel equipment air demand is 33% lower. The total costs (operational, maintenance, fuel and acquisition) are 29% lower.

3. Results and Discussion

In underground mines, in-depth work is subject to higher temperatures, mainly due to increased virgin rock temperature with depth, impacts of autocompression, as well as the heat released by the machinery used. Heat sources in a mine can be divided into two distinct groups: the first includes sources that depend on the geographical location of the mine and, therefore on the strata rock, called as natural sources of heat and the second comprises sources derived from human activities. The main underground heat sources are: autocompression (it isn't necessarily a heat source, but a process of energy change. Air is increased when it flows downwardly inside the mine which generates a temperature increase), fans, diesel fleet and the rock itself.

The estimation of thermal load in mines in deepening is the first step towards achieving the objective of estimating adequate airflow rates and cooling needs according to thermal comfort parameters. The thermal load of a mine depends on its location, operating equipment in operation and other heat-generating processes that occur on site. The factors that have the greatest heat flow potential are the surface areas, where heat transfer occurs to the mine, the gallery walls, the mine arrangement, and the working face.

The most efficient way to minimize the heat flow from rock to mine is to reduce the surface area. Galleries of exhausted areas that are no longer needed for mining operations should be closed or sealed. By doubling the mining rate on the panels, the total working face distance can be half for the same production. In terms of heat flow, this means an increase in the rate of heat flow per meter of ploughed panel of about 40%. However, as a result of reducing the total length of the panel face, the total heat flow is reduced by 30%. The effect of filling is interrupted and increases the mining rate of the face in the heat transfer on panels, shown in Figure 3. In deep mines the transfer of heat from rock to environment corresponds to more than 75% of the total heat generated in the mine (Wagner, 2010). However, in the mine under study, in the year (2019), the temperature of the rock is not significant. Already in 2026 due to the effects of autocompression and increase of the rock temperature mine (it will become significant) control measures should be taken and planned in advance. The heat reduction strategies discussed in need of:

- isolation of exhausted areas;
- filling mined areas with hydraulic backfill;
- introduction of thermal insulator on the walls of the gallery;
- increase in mining rates and concentration of mining operations;
- insulating systems for the transport of rocks and /or separation of the transport route of rocks from the adduction air;
- using few input ducts with large cross sections to minimize heat transfer from rock to the environment;
- use of the cooling zone around the inlet ducts.

From the detain Tables 2 and 3, it was possible to determine the sensitive and latent heat of trucks and loaders and the contribution of each heat source including fans, blasted rock and virgin rock. Table 4 shows the results for the current situation (diesel, loaders and trucks), while Table 5 show the results after the suggested change, chargers and electric trucks instead of diesel.

Table 4 – Heat generated using trucks and diesel/ loaders.

Heat source	Sensitive heat (kWh)	Latent heat (kWh)	(%)
Machines	5,866	3,61.5	80%
Fans	1,050		14%
Blasted rock	-		4%
Virgin rock	-	-	2%
Total	7,363		100

Source: Costa (2019).

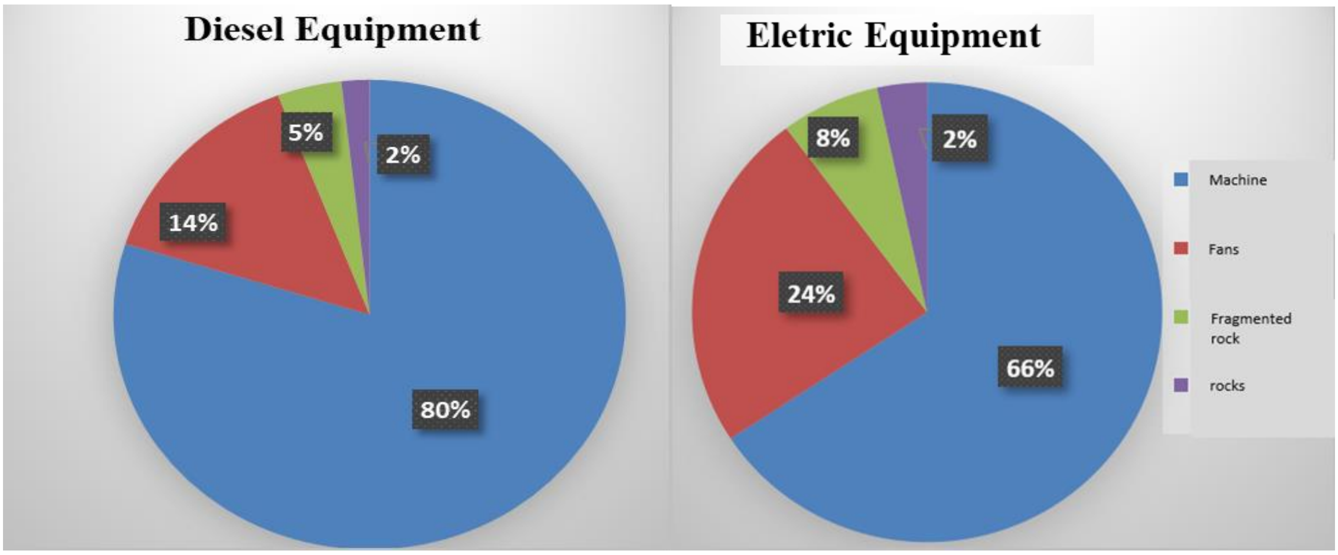
Table 5 – Heat generated using trucks and eletric loaders

Heat source	Sensitive heat (kWh)	Latent heat (kWh)	(%)
Machines	2,873.3	143.67	40%
Fans	1,050		14%
Blasted rock	-		4%
Rock	-	-	1%
Total	4,370.3		100

Source: Costa (2019).

Through Tables 4 and 5 the percentage of sensitive and latent heat was determined by the main heat source represented in Figure 2. There is a 41% decrease in the heat erased by diesel equipment. The sensitive heat and latent heat decrease 59% and 88%, respectively. Only loaders and trucks were changed. There are mines in which all fleet are composed by electric machinery, as Borden Mine, as mines with gradual change to this condition, as Kittila or Kiruna Mine. At those, the miners report the air quality improvement and less heat generation and vibrations. The Kittila’s company had decided on the use of battery-electric and electrified equipment five years ago, it would have likely deepened the shaft further and redesigned the mine to suit the reduced ventilation needs and required battery charging/changeout infrastructure (Gleeson, 2019). In Borden Mine 98% of operators reported a significant improvement in air quality (Calnan and Young, 2018).

Figure 3 – Heat difference generated, in percentage, between diesel and electric trucks in the mine.



Source: Costa (2019).

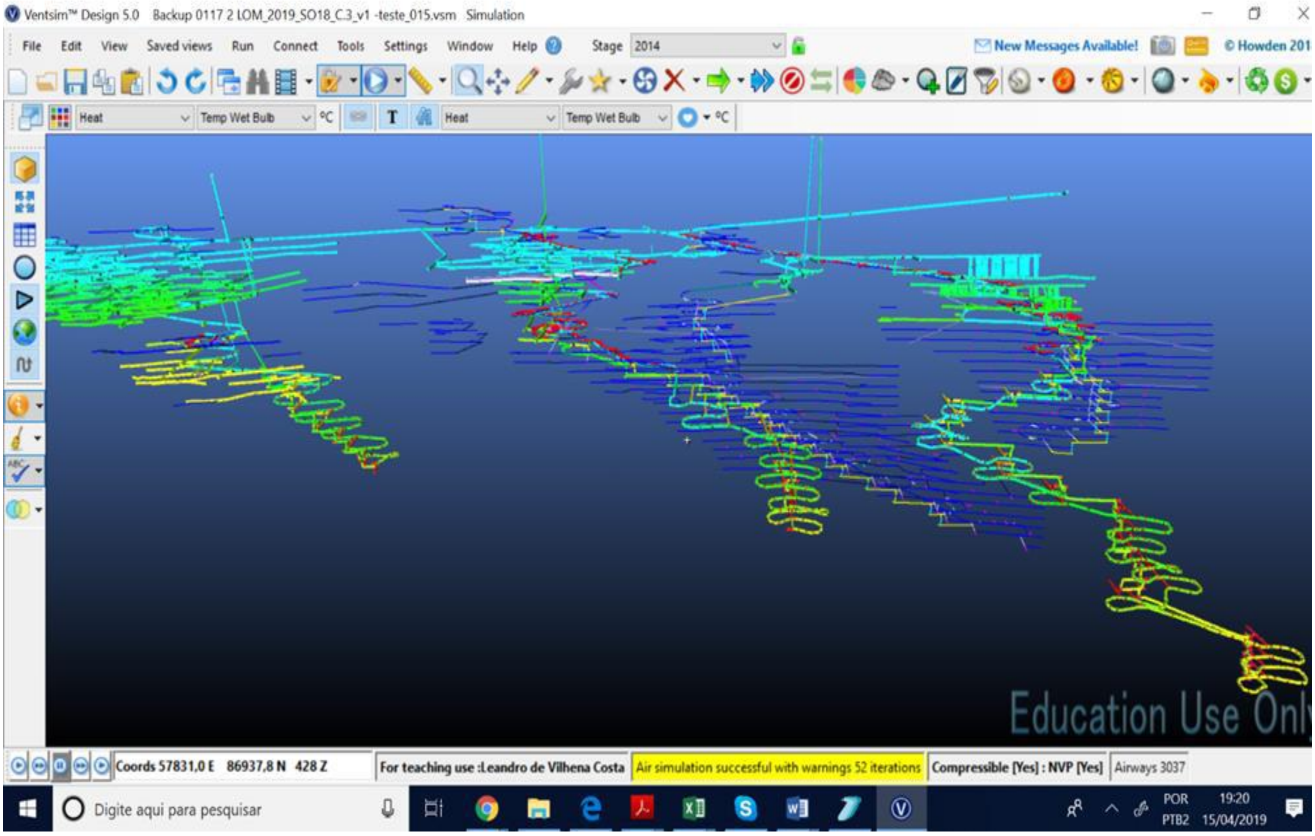
Table 6 – Summary of heat generated by each equipment of case study mine.

Type	Heat unit (kWh)		Total sensitive heat (kWh)		Sensitive heat difference (%)	Total latent heat (kWh)		Latent heat difference (%)
	MD	ME	MD	ME		MD	ME	
Truck	385.6	90	4,075.5	1,222.65	68.7	2,228.7	0	-
Loader	383.4	156	1,590.5	1,178.8	37.5	884.4		-
Jumbo	25.1	-	48	1	-	27	2	-
Auxiliary equipment	25.1	-	96	1	-	54	2	-
Total			5,693	2,873.3		6,248		

Source: Authors.

In relation to the hypothetical change a point that should be considered is that if these machines need power cables for their operation, the reduction of operational flexibility is significant. However, the most advanced models already have battery with 4 hours autonomy which makes this option quite attractive (Paraszczak, 2014). The Figure 4 show the temperature variation in the study mine. The results achieved are similar to work carried out by (Bascompta et al., 2016) carried out in a potassium mine where the diesel fleet is the main heat source with 74%. The decrease in sensitive heat was 49.4% and latent heat was 84.2%. The heat of the equipment decreased from 73.8% to 51.85%. Figure 5 show the percentage of heat generated by the main sources and heat.

Figure 4 – Arrangement of the studied mine. Yellow, green and light blue colors represent damp bulb temperature.



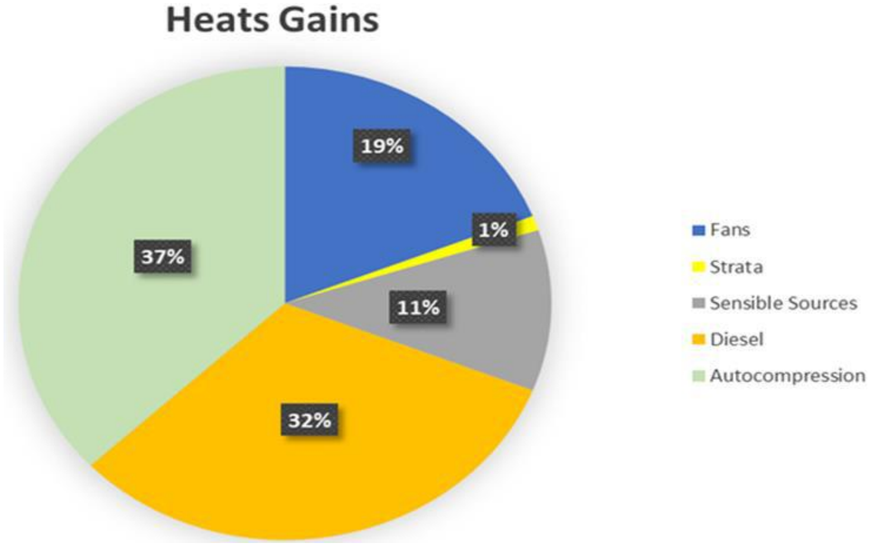
Source: Costa (2019).

The use of diesel oil as fuel in underground mines causes a warmer environment due to the generation of toxic gases and higher ventilation demand for dilution of these gases. Electric LHD has two models available on the market, one cable-connected in the mine electrical system and the other battery charged, and the two models provide a near extinction of excessive heat generation problems caused by diesel-powered machines and toxic gases.

Pinto (2018) mentions that the use of electric LHDs presented satisfactory results not only for the well-being of the worker, but also drastically reduced the energy consumption of the ventilation system, reducing ventilation costs from 33% to 60%, when well scaled. The cable model proved less advantageous compared to battery due to its reduced mobility and cable maintenance quite expensive, making better battery LHDs.

Gwyn, quoted by Jensen (2013) describe that the deeper the ore and equipment enter the crust, less profitable become using machinery that works with diesel technology due to the large amount of ventilation infrastructure needed to keep the work environment safe. In addition, he also considers removing diesel a great advantage, as it would completely alleviate the problem of emissions from diesel engines, in addition to reducing the heat and noise generated by them.

Figure 5 – Percentage of heat generated by the main sources and heat (result of Ventsim simulation considering autocompression).



Source: Costa (2019).

4. Conclusion

The use of electric loaders and electric trucks decreases the generation of sensitive heat by 39% and latent heat around 61% in the study conducted. Overall, the contribution of heat of machines decreased from 80% to 66%. In addition, the model allowed to know the heat behavior of the strata in the gold mine, discovering the trend of sensitive and latent heat. It would be advisable to combine electrical and diesel equipment with and would maintain the same operational flexibility. The use of diesel oil as fuel in underground mines mainly entails a warmer confined environment, a polluted air with substances toxic to human health and higher financial cost of the mine in order to alleviate these problems. The diesel equipment presents more flexibility and greater mechanical power than electric one, but in future these questions should be solved.

The increase in the route (DMT) as the mine deepens will require an increase in number of trucks and, consequently, increased heat generation increased due to increased fuel consumption and toxic gas generation. The use of electrical equipment can also help offset uncertainty about oil price variations and more restrictive environmental legal requirements.

Due to the difficulty in the implementation of electrical equipment due to the high costs of acquisition, replacement of the existing fleet, maintenance, operational efficiency, in addition to the infrastructure adapted to these equipment other alternative can be tested as: refrigeration plant (in case more extreme), construction of an adduction shaft in order to improve heat exchanges, use of trucks and autonomous loaders removing operators from the areas hot and inappropriate for work; avoid the accumulation of equipment at a given point. These options are viable and practical alternatives to alleviate the future problem.

The simulations show that the participation of the rock is very small with approximately 1% in the current year (2019), but in 2026 the contribution will increase to 9%. The most effective alternative to reduce heat flow is surface area. The oldest galleries that are no longer necessary for mining operations must be closed or filled with some insulating material. Knowledge of virgin rock temperature and knowledge of its thermodynamic characteristics are important for a more assertive dimensioning of ventilation, in addition to the definition of strategies that minimize the problems related to the heat generated by the rock.

The decrease in heat load would allow for greater energy efficiency due to less need for ventilation and better work environment; consequently, it would increase the worker's performance due to the lower effective temperature and generation of combustion gases. Beside these ways, there are other possibilities in operational practices to reduction of heat in underground mines showed in this paper. Other way is the increase of automation.

Application of thermal sensors and the application of the ventilation of demand allow to determine the most critical regions and reduce the exposure of diesel gases, consequently the generation of heat, because of the addition of flow that can be allocated in areas with high concentration of pollutants. This allows actions to mitigate problems with high temperatures. The search for less polluting fuels, such as S10, favors the reduction of heat, which requires less cost with ventilation. Poor ventilation on the mining fronts is one of the main causes of high temperatures and accidents in underground mines. When ventilation is poor, high temperature can affect the physical and mental health and work efficiency of mine employees.

The Calculation of the heat of each specific source, in addition to comparing between software and equations, presented in this paper, cand aid improving of ventilation in mine or new design. The mines cited in this paper verified their ventilation systems and, by chances to electric got new values of costs.

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