Modeling the variation of psychrometric properties of air in depth.

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Abstract

This Master of Science Thesis (dissertation) was developed in the SOMINCOR Ventilation Area with the aim of identifying and modeling dynamic mathematical relationships between psychrometric properties (dry and humid temperatures and humidity) of the clean air admitted by the Ventilation's Principal Chimneys (CPV), and the psychrometric properties (dry and wet temperatures and humidity) of the air in the underground environment.

The present work fulfilled the proposed objective with the development and implementation for MATLAB of dynamic mathematical models to support the time prediction of psychrometric variables determining the thermal comfort (dry temperature and relative humidity), a necessary and sufficient condition to be able to predict other properties of the air (wet and dew point temperatures).

Specifically, a semi-empirical model (Modified Newton's law of cooling/heating) for the convective heat transfer air-rock, a semi-empirical model for the increase of the air temperature by adiabatic auto-compression of the air column, and an empirical model (NARX model), based on two-layer neural network, as a transfer function for the relative humidity of the air.

These contributions aim to support the future implementation of a predictive control strategy, an advanced process control variant based on the use of models to predict the future trajectories of controlled variables (dry temperature and relative humidity at depth levels) as a function of values of the manipulated variables (air dry temperature at the surface), being these values determined by formulation and resolution of a constrained optimization problem.

Keywords: Modified Newton's Law of Cooling/Heating; Underground atmosphere; Adiabatic auto-compression; Data Science.

1. Introduction

Mining engineering, when compared to other branches of industry, is always faced with the inflexibility of the factor that is the location of its operations. This imposition, conditions, from the beginning, a series of variables, which preside over the ventilation operation. Among many other factors, one can highlight the depth of the work and the geomechanical and geothermal characteristics of the ore body, which determine the underground infrastructure to be implemented.

Thus, the design of ventilation networks is required not only to predict the function, but also to correct situations, in order to optimize the entire process in terms of energy efficiency and associated cost.

Sometimes situations appear during the life of the mine, such as the discovery of new mineral deposits and changes in legislation related to the work in the underground environment, which require changes in order to continue to ensure the air needs at each mine site.

The complexity of underground work at the Neves-Corvo Mine has led to the creation of a complex and extensive ventilation network.

The main objective of this dissertation is the determination of a numerical model, that allows to relate the variation of the temperature and relative humidity of the air between the surface and different places in depth along a chimney of admission of fresh air (CPV- *Principal Chimney of Ventilation*). For this purpose Wet and Dry Temperature, Relative Humidity, Heat Stress Index were recorded as well as Condensation Temperature (Dew Point) and Stationary Pressure, all synchronously in different locations.

The different physical parameters of the air allow the study of the thermodynamic variations of this fluid in depth, under the action of the geothermal gradient and the adiabatic auto-compression, something intrinsic to underground chimneys.

Through data from the in situ readings and computational processing it becomes much simpler to simulate the reality from information from the case study itself, from CPV22 of the Neves-Corvo Mine.

2. Background

The atmospheric air that enters the underground environment gradually increases its temperature, as the depth of the place where it flows to increases, and the main cause for that is the heat transfer from the virgin rock due to the geothermal gradient. Other sources of air heating in the underground atmosphere are adiabatic self-pressure, the operation of diesel-powered equipment, explosive charge detonation, the presence of thermal water and the human metabolism itself [3].

In the case of CPV22 study at the Neves-Corvo Mine, the operation of diesel equipment, explosive charge detonation, human metabolism and thermal waters can be excluded from the heating factors of the underground atmosphere, because this chimney is isolated from this type of activities, since access to the sections of the chimneys is done in galleries assigned to the air passage, and any activity within it is sporadic and of short duration.

$$\Delta T_{total} = \Delta T_a + \Delta T_r + \Delta T_d + \Delta T_e + \Delta T_h + \Delta T_w \quad (1)$$

ΔT_{total} total temperature change in the underground environment

ΔT_a temperature variation by self air compression

ΔT_r thermal properties of the rock

ΔT_d heat emission from diesel equipment

ΔT_e heat emitted during detonation of explosive charges

ΔT_h heat emitted by human metabolism

ΔT_w heat emitted by the thermal waters of the ore body

Vidal Navarro and Dinis da Gama in 2008 [7], pointed out that with the increase of exploration depths, the influence of the thermal properties of the rock, ΔT_r, become more important, such as the study of geothermal gradient variation. We can base the temperature of the underground atmosphere, ΔT_{sub}, on the equation 1 if we add the function of the meteorological temperature to the surface, T_s, ie:

$$T_{sub} = \Delta T_{total} + T_s \quad (2)$$

Surface air temperature

The surface air temperature, or weather temperature, oscillates with the diurnal variations, with the seasons of the year and with the climatic regional variations.

The closest work stopes to the surface (depth <750-770m) or places with direct surface air admission express a direct correlation between the dry surface air temperature and relative humidity, and the dry temperature and relative humidity at the work sites, thus the higher temperatures of the warmer months have a critical influence on the thermal comfort of workers, in 2018 the hottest day of the year reached $45.2°$ C dry temperature on the surface which translated into $41.7°$ C at N700GV2, 490m in depth.

Variation of air temperature by adiabatic transformation (self-compression / expansion)

The self air compression is a process that occurs during the descent of the air through the underground openings and due to its own compression. The mathematical equation of the air temperature variation due to the adiabatic self-compression ΔT_a, whose deduction can be seen in V. Navarro, Dinis da Gama and N.Singh [7] is defined by the following expression:

$$\Delta T_a = T_2 - T_1 = \frac{(\varrho - 1)h}{\varrho . R} \quad (3)$$

Entering the numerical values of the perfect gas constant and the adiabatic (average) coefficient of the air, $R = 29,27 kgfm/kg°C$ and $\varrho = 1,302$, respectively:

$$\Delta T_a = T_2 - T_1 = 0,0098h \quad (4)$$

This simplification can be deduced using the laws of physics and assuming that the studied air is an ideal gas mixture. In an adiabatic expansion, the first law of thermodynamics becomes $dU = -dW$. The internal energy U is proportional to T, so the temperature decreases with adiabatic expansion and rises with adiabatic compression. When a gas expands in a thermally insulated container, it cools, when it is compressed, it heats.

$$pV^{\gamma} = p_0 {V_0}^{\gamma} = constante \quad (5)$$

Where (p_0, V_0) are the initial pressure and volume values, respectively, for an ideal gas. The constant γ is calculated by:

$$\gamma \equiv \frac{C_p}{C_V} \quad (6)$$

In gases and mixtures of ideal diatomic gases $\gamma = 1,4$ [5]. C_p and C_V are the thermal capacities ($J/°C$) at pressure and constant volumes, respectively. Knowing the ideal gas equation, $pV = nRT$:

$$\begin{aligned} PVV^{\gamma-1} &= P_0 V_0 {V_0}^{\gamma-1} = constante \\ \frac{PV}{nR} V^{\gamma-1} &= \frac{P_0 V_0}{nR} {V_0}^{\gamma-1} = constante \end{aligned} \quad (7)$$

In terms of V and T, the transformation follows the function:

$$TV^{\gamma-1} = T_0 {V_0}^{\gamma-1} = constant \tag{8}$$

Equation of ideal gas states

$$\begin{aligned} V &= nR\frac{T}{p} \\ p\left(nR\frac{T}{p}\right)^{\gamma} &= p_0\left(nR\frac{T_0}{p_0}\right)^{\gamma} = nR \\ p\left(\frac{T}{p}\right)^{\gamma} &= p_0\left(\frac{T_0}{p_0}\right)^{\gamma} = nR \end{aligned} \tag{9}$$

In an adiabatic transformation (in a thermally isolated system) if we assume that air is an ideal gas, these concepts can be quantified. Assuming that the pressure, p, and the temperature, T, are related by adiabatic transformation. The adiabatic curve $p-versus-T$ is given by $p^{1-\gamma}T^{\gamma} = constant$ which can be solved for T:

$$T = (constant)p^{\frac{\gamma-1}{\gamma}} \tag{10}$$

Differentiating equation 10, applying the chain rule, comes:

$$\begin{aligned} \frac{dT}{dz} &= \frac{dT}{dp}.\frac{dp}{dz} = \\ &= constant \times \left(\frac{\gamma-1}{\gamma}\right)p^{\left(\frac{\gamma-1}{\gamma}\right)} - 1\frac{dp}{dz} = \\ &= \left(\frac{\gamma-1}{\gamma}\right)constant \times p^{\left(\frac{\gamma-1}{\gamma}\right)}p^{-1}\frac{dp}{dz} \end{aligned} \tag{11}$$

with the final form,

$$\frac{dT}{dz} = \left(\frac{\gamma-1}{\gamma}\right)Tp^{-1}.\frac{dp}{dz} \tag{12}$$

It is assumed that air obeys the ideal gas law in this case, is not an incompressible fluid. Simply put, the pressure variation with depth can be described by the following equation:

$$\frac{dp(z)}{dz} = \rho_{ar} g \tag{13}$$

The variation with pressure, that is, specific mass independent of T, is defined by:

$$\rho_{ar} = \frac{m}{V} = \frac{nM}{V} = M\frac{p}{RT} \tag{14}$$

with $p(z_0) = p_0$ and substituting the equation 14 into the equation 12 one obtains:

$$\frac{dT}{dz} = \left(\frac{\gamma-1}{\gamma}\right)Tp^{-1}\left(\frac{Mg}{RT}\right)p = \left(\frac{Mg}{R}\right)\left(\frac{\gamma-1}{\gamma}\right) \tag{15}$$

Knowing that $M = 0.029kg/mole$, $g = 9.8m/s^2$ and $R = 8,3J/°C$, it is calculated:

$$\begin{aligned} \frac{dT}{dz} &= \left(\frac{0,029kg/mole\,9,8m/s^2}{8,3J/°C}\right)\left(\frac{1,4-1}{1,4}\right) = \\ &= 0,0098 \approx 0,010°C/m \end{aligned} \tag{16}$$

Air is a reasonable thermal insulator so the vertical variation of the air can be described as adiabatic. When the air rises, the pressure decreases, the air passes through an adiabatic expansion, and its temperature drops. When the air is carried downwards undergoes adiabatic compression, the temperature increases.

The temperature variation rate of $0.0098°C$ per meter of depth overestimates the increase in air temperature by adiabatic self-compression. In the case of the adiabatic expansion of air at altitude, the experimental result is $0.0065°C/m$, ie 65% of the theoretical value, this difference may be due to the effects of condensation of air in the atmosphere and the effects of topography (embedding geometry) in the progression of air masses. In the case of openings of length L, inclined from an angle α with the horizontal, the vertical height h is equal to $L\ sin(\alpha)$ And the final equation to obtain the increase of the temperature of the underground atmosphere by adiabatic self-compression is:

$$\Delta T_a = 0,0098L\sin(\alpha) \tag{17}$$

When $h = 1.0m$ depth the temperature increase for this meter is $0.0098°$ C, that is for every 100 m of depth the air temperature increases by $0.98°C$ or approximately $1°C$.

Summarizing, and given the horizontal inclination of the underground openings (α), this increase in temperature is much more noticeable in vertical wells than in sloping openings or ramps and obviously in horizontal openings where it is zero.

Geothermal gradient - convective heat transfer

The geothermal gradient, gg, is the rate of the increase in temperature of the constituent materials of the Earth as a function of depth (following a downward progression from the surface towards the Earth's core). In regions far from the boundary between tectonic plates, the average global value of this gradient is about 30 $°C$/ km depth (1 $°C$ for every 33 m of depth or 3 $°C$/ 100 m of depth). At the Neves-Corvo Mine the most recent studies indicate an increase in temperature with depth, temperatures of 64 and 130 $°C$ at 2 and 5km, respectively, according to data published by LNEG in 2018 [6], these values are translated by the increase of 1 $°C$ by 29.4 m or 34 $°C$ by 1000 m.

Knowing the geothermal degree, ($m/°C$), the temperature of the thermal neutral zone, T_{cn} ($°C$),

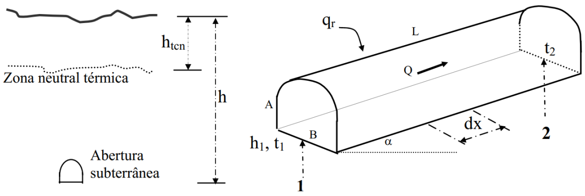

Figure 1: Scheme with the exemplification of the quantities used to calculate the temperature variation caused by the geothermal gradient, an image taken from the 2005 publication of Vidal Felix Navarro Torres and Carlos Dinis da Gama [3].

the thickness between the surface and the thermal neutral zone of the Earth's crust, h_{tcn}, (m), the temperature of the rock mass to a certain depth, h, the temperature rise of the called country rock, T_{hr} ($^{\circ}C$), is given by:

$$T_{hr} = T_{cn} + \frac{(h - h_{tcn})}{gg} \tag{18}$$

With this equation and the denotation of parameters of the figure 1 we derive the equation 19 which expresses the temperature increase due to the geothermal gradient $\Delta Tgg(^{\circ}C)$, where h_1 is the final depth of the chimney section (in the gallery's crown) from the surface (m), L the length of the subterranean aperture (m), α the slope of the section.

$$\Delta T_{gg} = \frac{(h1 - h_{tcn}) \pm L\sin(\alpha)}{gg} \tag{19}$$

2.1. Newton's Cooling / Heating Law Modified

In the late 17th century, British scientist Isaac Newton studied the transfer of heat in cooling bodies. Experiments have shown that the cooling rate is approximately proportional to the temperature difference between the warm (heated) body and the ambient. This fact can be described by the differential equation:

$$\frac{dQ}{dt} = \delta A\left(T_S – T\right), \tag{20}$$

where Q is the amount of heat, A is the surface area of the body through which heat is transferred, T is the temperature of the body, T_S is the temperature of the environment , δ is the convective heat transfer coefficient that varies as a function of body geometry, surface state, heat transfer mode and other factors. Since $Q = CT$, where C is the heat capacity of the body, one can write:

$$\frac{dT}{dt} = \frac{\delta A}{C}\left(T_S – T\right) = k\left(T_S – T\right). \tag{21}$$

The given differential equation has the following solution:

$$T\left(t\right) = T_S + \left(T_0 – T_S\right)e^{-kt}, \tag{22}$$

where T_0 indicates the initial body temperature.

Thus, while it cools, the temperature of any body approaches exponentially the temperature of the surrounding environment. The cooling rate depends on the parameter $k = \frac{\delta A}{C}$. With the increase of the parameter k (for example, due to the increase of the surface area), the cooling occurs faster.

Accordingly, with Newton's law the incoming air "cools", or heats, at a constant rate, k, however, the ambient temperature increases by the linear relation:

$$T_r = T_{r0} + \beta t, \tag{23}$$

First, one should emphasize the difference with the original law where the environment temperature is constant. In the case of study of the Neves-Corvo Mine, the air inlet temperature in the mine is approaching the ambient temperature, for an indefinite time.

The cooling / heating process (heat transfer) can be described by the following differential equation:

$$\frac{dT}{dt} = k\left(T_S – T\right). \tag{24}$$

In the case of the underground environment $T_S = T_{S0} + \beta t$, the variation is described by Eq. (23). Thus, the last equation can be written as follows:

$$\begin{gathered} \frac{dT(t)}{dt} = k\left(T_r(t) - T(t)\right) = \\ = k\left(T_{r0} + \beta t – T(t)\right) = kT_{r0} + k\beta t - kT(t) \end{gathered} \tag{25}$$

The equation 25 can be rewritten as:

$$\frac{dT(t)}{dt} + kT(t) = kT_{r0} + k\beta t \tag{26}$$

With $T_r(t=0) = T_S$ defining the initial condition we obtain a first-order linear differential equation, whose resolution is done by the integrating factors method [2]. Details of the application of the method to resolution of the equation 26 can be seen in [1].

The general solution of the equation 25 or 26 is written as

$$T\left(t\right) = T_{r0} + \beta t – \frac{\beta}{k} + \left(T_s – T_{r0} + \frac{\beta}{k}\right)e^{-kt} \tag{27}$$

as a function of the contact time t, or as

$$\begin{gathered} T\left(z\right) = \\ = T_{r0} + gg \times z – \frac{gg \times v_{ar}}{k}\left(T_s – T_{r0} + \frac{gg \times v_{ar}}{k}\right)e^{-k\frac{z}{v_{ar}}} \end{gathered} \tag{28}$$

in function of the z depth quota.

3. Methodology

The methodology of this thesis does not fit in the classic molds of an experimental methodology since it does not have an extensive, more or less varied list of materials, nor a procedure approved by a scientific institution of the area to obtain reproducible results, this is largely due to the constant change in industrial activity, which are the mining operations of development and production, but mainly due to the lack of recent research into mining ventilation, despite its importance in human health and the achievement of good production results.

CPV22 (Figure 2) is currently the only main fresh air intake chimney for the mineralized body of the Lombador that extends vertically from 400m deep to 1200m, with an average inclination of 35 degrees and an extension of 1400m and that at the moment has development works at depths greater than 1km.

Due to its length and depth, the Lombador presents new challenges for the maintenance of an underground atmosphere with only mechanical ventilation and control of traditional air sources, so it is of the greatest interest to prepare the possible installation of an air cooling plant and the course that cooled air can do, as such it is necessary to study the current surrounding environment.

For the study of the underground atmosphere only 3 Kestrel sensors were available, as it was decided to install the 3 along CPV22, the 1st to the surface - Sensor 17, the 2nd sensor - Sensor 21 - on the basis of the 1st vertical section thus obtaining the direct variation (without changes of direction) and finally the 3rd sensor - Sensor 25 - in the place (with access) deeper and that characterizes the air supply to the most critical work zones , as well as air after having completed CPV22 in all its extension (sections + ventilation galleries). The spatial distribution of the 3 devices can be visualized in the figure2.

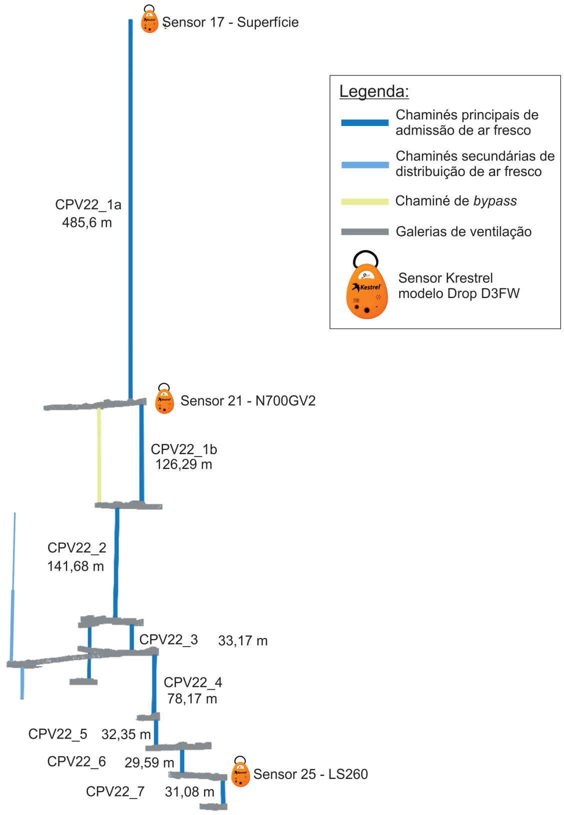

Figure 2: 3D model of the geometry of CPV22 and respective ventilation galleries. Presentation of the vertical length of the sections in meters (m).

4. Results & Discussion

The survey of measurements began on May 21, 2018 with the installation of the 3 sensors in the locations mentioned in the previous chapter, only being extended until August 16, with some hiatus due to lack of battery in the devices and a loss of information in the smartphone cache after the collection. As such, the sampling periods considered valid, ie with the 3 sensors installed locally and operationally, were:

- between 21 May and 1 June;
- from 4 June to 27 July
- and from August 2 to 16 (this last interval can be shortened to August 10 to 16, as an error occurred in the sensor 21 and no longer correctly measured the values of relative humidity, and wet temperature affecting also the calculation of Heat Stress Index and the dew point temperature of the apparatus during that failure period the dry temperature or stationary pressure measurement were unaffected.)

In order to understand the thermal oscillations that respect the annual seasonal variations naturally imposed by the meteorological variability, smaller time series with average temperatures similar to the "classic" seasons (Spring, Summer and Autumn) were defined.

In the figure 3 it is represented the summer season with data collected from 3 to 16 of August. After the end of the recording of the data, it was necessary to find an algorithm or formula that relates and describes the behaviour and differences of the temperature of the air in depth, taking into account the unique behaviour of the air in this environment.

The most important result is the one presented below, with the graphical representation of Newton's Cooling Law applied to the case study.

The most important step for the application of this law was the development of the MATLAB code that allows the modelling of the N700GV2 and LS260-CPV22 levels using only the meteorological temperatures. The programmed results allow the

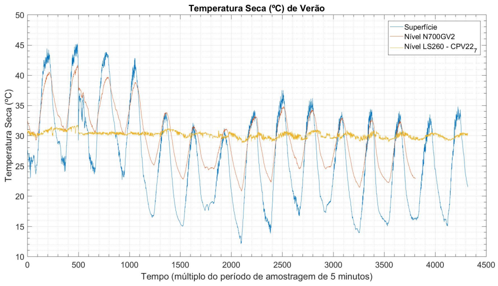

Figure 3: Schedule with dry temperatures, in the 3 levels studied, during a typical summer period.

automatic generation of dry temperature forecasts for these levels with a high approximation to the reality, figure 4. The algorithm was started with the reading of the data provided and with the numerical definition of the geothermal gradient to be used, as well as the surface temperature of the rock, that is, the theoretical value for the crust neutrality zone.

After defining the universal characteristics, all air influence parameters were established in the 1st section, that is, in CPV22-1a. This step defined the direct influence of the adiabatic autocompression and geothermal gradient without any influence by decompression on horizontal displacement, thus modelling the first sampling site.

The next step was the application of the resolution of the Least Squares Method for estimation of the time constant k, for modelling Newton's Cooling Law previously quoted and adapted, with the temperature of the environment not constant. Also included was the development of an initial search grid for refinement. The combination that minimizes SQE is $Tr = 13°C$ and $k1 = 1min^{-1}$. Note there is a wide range of optimal values, with values very close to the minimum value of SQE, so the minimizer is global but very little sensitive to variations of Tr and $k1$.

Then the Least Squares Method was applied to the adjustment of the time constant k of the Newton's Cooling Law to the subsequent sections, setting the value of Tr to the adjusted value for the first section. Consequently the following algorithm was intended to calculate the time constant for the next sections of CPV22. The value that minimizes SQE is $k2 = 0.3min^{-1}$. The minimizer is global and unique.

4.1. NARX model for Relative Humidity

The relationship between relative humidity of air at the surface and at deep sites along ventilation shafts was developed using Artificial Neural network (ANN) or Redes Neuronais Artificiais (RNA) in Portuguese.

For the case study the Neural Network Based System Identification Toolbox was used through numerical calculation software, MATLAB. The network was calibrated through the back-propagation algorithm using the Levenberg-Marquardt optimization method. The training, testing and validation of the model were performed with a data set corresponding to a 50/50 partition of the complete random sampled data record for the month of May 2018.

For the operation of the neural network processing unit, called a neuron, is essential. Artificial neuron is the basic component of RNAs. Like the biological neuron, the artificial neuron has one or more input signals and only one output signal. The input signals (stimuli) must reach the neuron simultaneously, ie all information must reach the nucleus of the artificial neuron at the same time [4].

A demonstration was used to show that a NARX model can be used to model a second order nonlinear dynamic system. To generate the model, a group of raw data related to the parameter Relative Humidity was inserted.

For this NARX model 4 input variables (stimuli) were used, connected to 5 neurons in the hidden layer with transfer function or hyperbolic tangent function, which communicate with 1 neuron in the output layer.

The purpose of the Toolbox is to show how the NARX function can be used to model non-linear dynamic systems. To generate the model, a raw dataset must always be inserted. The next step is for the Toolbox to choose the network architecture and the regressor structure. The regressors chosen were two input neurons and two output neurons and a network architecture with 4 neurons in the hidden layer with the transport function being the hyperbolic tangent. After the decision, the training, or calibration, of the neural network constructed using the Levenberg-Marquardt algorithm is started, after the calibration a prediction model can be obtained. This sequence was repeated for the two levels under study.

The model with a future forecast of 50 min (10 steps ahead with 5 minutes each) for level N700GV2 is shown in fig. 8 and for level LS260-CPV22 in fig.9. Since the neuronal network had a better adaptation to the classic polynomial behaviour of level 700, than in the level 260 that presents a high entropy in the Measurements of Relative Humidity, what causes an adaptation of the neural network to an average of values inferior to the reality.

The Toolbox also allowed the construction of the histograms with the relative frequency of prediction errors of each model according to the number of steps ahead (figure 10).

The error correlogram from the prediction of the relative humidity of level N700GV2, can be considered white noise due to its low values, this is an

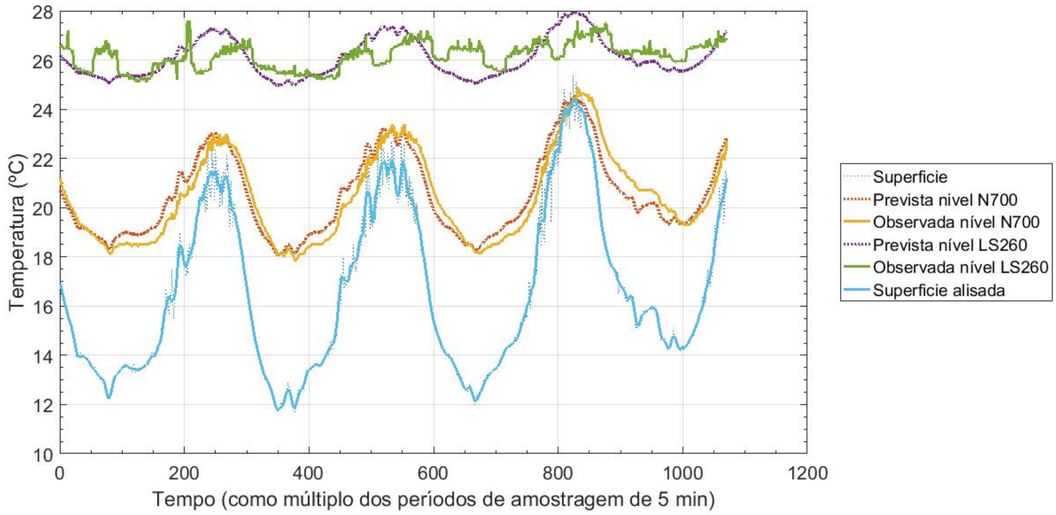

Figure 4: Schedules of measured and predicted dry temperatures at the sampled levels.

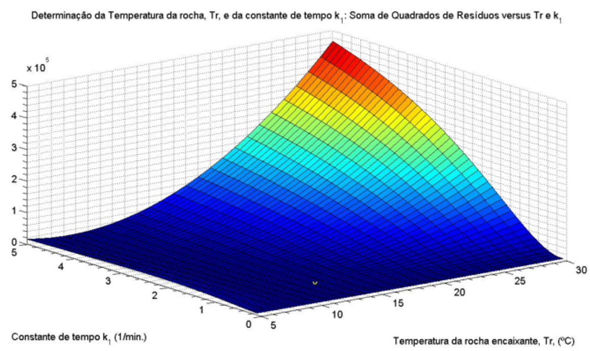

Figure 5: Parameter adjustment: Sum of square errors (SQE) as a function of Tr (rock temperature in the ”neutral zone”) and the time constant k for the first section, (k1).

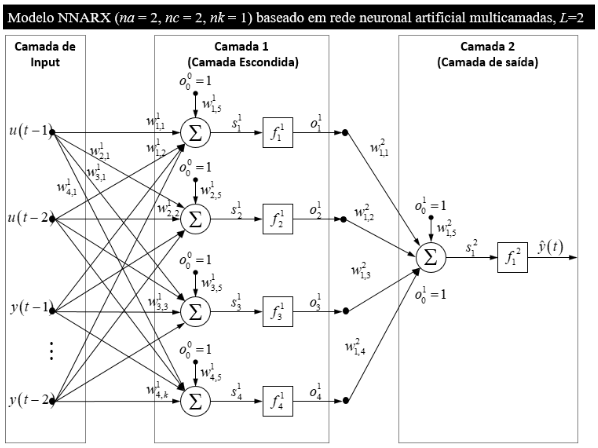

Figure 7: Structure of the multilayer two-layer neural network used for the NARX model.

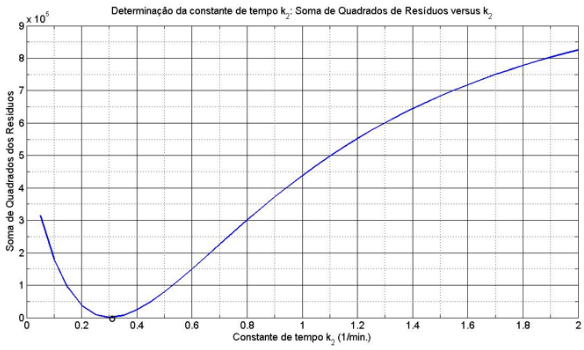

Figure 6: Parameter Adjustment: Sum of Squares of Errors (SQE) as a function of the time constant k for the subsequent sections (k2).

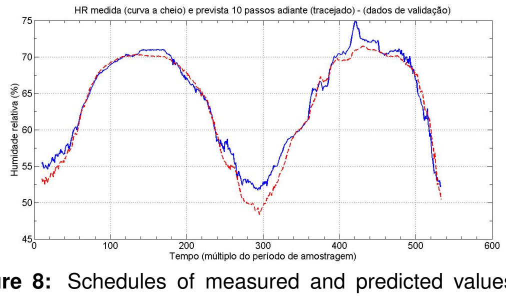

Figure 8: Schedules of measured and predicted values 10 steps ahead of Relative Humidity (%) of the N700 level.

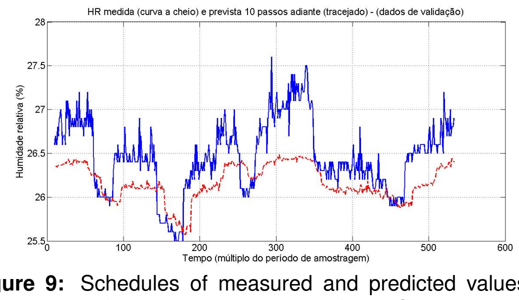

Figure 9: Schedules of measured and predicted values 10 steps ahead of Relative Humidity (%) of the LS260 level.

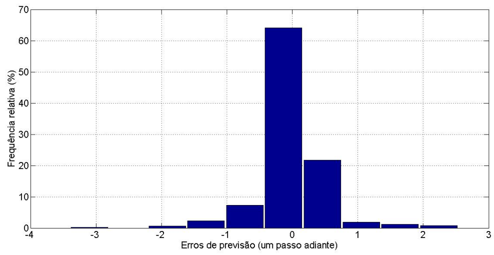

Figure 10: Histogram of prediction errors one step ahead of Relative Humidity (%) of level 700.

indication of the good quality of the model.

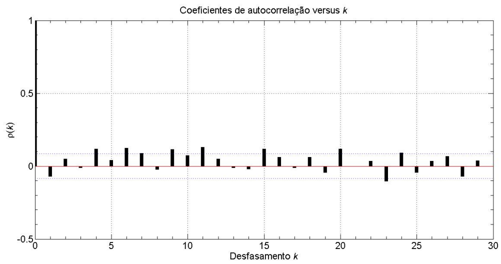

Figure 11: Correlogram of prediction errors, at level 700.

5. Conclusions

The current work was developed in SOMINCOR - Sociedade Mineira de Neves-Corvo and was carried out in a business environment, which allowed a more objective understanding of the needs of the Ventilation area to obtain thermal comfort in all work fronts.

By observation of the present study, it is concluded that all the proposed objectives were fulfilled, except the objective of the evaluation of the model developed for each season of the year.

It was developed a MATLAB code that identifies the mathematical equation that correlates atmospheric (surface) air with the Dry Temperature underground atmosphere, which allows the development of optimization studies in the future. An Artificial Neural Network Toolbox for the prediction of Relative Humidity at the N700GV2 and LS260-CPV22 level was also applied to the case study, as long as the calibration data of the models were provided. With the knowledge of these two physical parameters (independent variables) other physical parameters of the underground atmosphere, such as Wet Temperature and Dew Point (or condensation temperature), can be calculated.

The results obtained in this dissertation can be defined as the use of helpful tools for data analytics, from the development of empirical analytical models (for example Newton's modified Cooling Law) to the application of machine learning through neural networks that self-develop semi-empirical models.

The developed works approached the area of Ventilation in underground mines in an unpretentious way, which led to the construction of tools that were not often used in Geological and Mining Engineering of the past, but which have been introduced in all engineering since data mining is currently a cross-cutting process that is indispensable to any study, with the exponential increase of available data. This departure from the comfort zone led to the deepening of the knowledge in MATLAB, and opened new horizons for the future.

5.1. Found limitations and Future Work

There were several limitations encountered, however they were all a real representation of the problems of a survey of data in an industrial environment, so educational to a certain extent. Some of these mishaps were the theft of devices, computer errors, and other failures of human nature.

However, as future work, it is important to evaluate these models for each season of the year, preferably using values measured over several years. Neural networks are a method that requires plenty of data to be obtained from a model that fits well every case study, since an increase in the number of available data may help to obtain a better performance in modelling the forecasting process.

The goal of this thesis was to understand the progression of the Dry Temperature in depth, this objective was reached through the modified Newton Cooling Law, however this result should be expanded and applied to the new fresh air intake temperatures obtained through an air cooling facility, on the surface of CPV22 (the silent objective). The most preponderant future work must therefore undergo a meticulous evaluation of this structure in order to understand what is the best solution for the underground atmosphere, considering that the geothermal gradient and the adiabatic self-compression do not change the weight of its increment with the decrease of the weather temperature through cooling.

If in the future there is a need to optimize the equations of the empirical model, the adiabatic decompression of the air with its arrival in the horizontal galleries (less confined than the ventilation chimneys) should be studied, and the possibility of studying the distance travelled by the air in chimneys, in the same way that it is studied its progression in ventilation sleeves considering an equivalent distance, that takes into account the friction of the changes of direction and the roughness of the surface, and finally adjust the geothermal gradient since this varies in depth with the characteristics of the rocky massif.

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