Technical Sciences
Academy of Romania
www.jesi.astr.ro

Journal of Engineering Sciences and Innovation
Volume 2, Issue 2 / 2017, pp. 92-104

E. Civil Engineering and Transporting Engineering

Some issues of thermal calculation of ventilation air for the metro

OMAR LAHCHAVA [1], NICOLAE ILIAS[2*]

[1] 0186, Mindeli Street 7, G. Tsulukidze Mining Institute, Tbilisi, Georgia
[2] Universității Street 20, University of Petroşani, Petroşani, Romania

Abstract. The paper reviews the main indicators for the calculation of the optimal consumption of ventilation air for the metro in case of necessity dilution of different harmful substances. The above-mentioned harmful effects are mainly caused by: the number of passengers; harmful and toxic gases released from the mountain massif, as well as the exchange of heat and moisture between the massif and the air. Ventilation thermal calculation is one of the central issues to determine the air flow with sufficient accuracy and to establish rate of air exchange in underground space. The paper describes calculation of the natural temperature of the mining area for both stationary and non-stationary fields. The work also gives the thermophysical and mass-physical characteristics of the main rocks. The characterization of these coefficients is also shown in the fields of temperature and mass transfer potential.

Key words: thermal calculation of ventilation, temperature of neutral layer, thermo-physical and mass-physical characteristics of the rocks.

1. Introduction

The air consumption in the subway ventilation system must to be calculated according to the following main indicators of underground facilities: the number of passengers; generation of harmful gases, heat and moisture under the ground, air exchange rate. There also takes into consideration the influence of natural traction on the subway ventilation. In particular, the rate of air exchange index is determined by the natural dynamic pressure. Finally, the largest amount of air defined by these factors will be taken for further consideration.
For establishing of ventilation parameters and selection of ventilator equipment, this calculation is practically implemented as follows: defining of air consumption

[*]Correspondence address: iliasnic@yahoo.com

according to the number of people - 1 person must have at least 50 m^3/h airs in conditions of "peak hour". As a rule, this amount of air is enough for breathing and ensured of evaporation from the body and assimilation of the moisture by the underground space, and according to the latest indicator, the air flow is no longer required. After this, it is necessary calculation air for the dilution to the safe concentrations of the hazardous gas emitted from the massif and the maximal indicator of the above results on the air amounts are taken for the following calculation.

Maximal consumption of air conditioned by these factors will be taken into account as based index and checked by the following formula according to the indexer of air exchange in the underground space

$$k = \frac{L}{V}, \quad (1)$$

where k is the rate of air exchange index; L - air volume consumption in hour (maximal of basing); m^3/h; V - total volume of metro underground space, m^3.

In case if the index of air exchange more then 3 (i.e. $k \geq 3$), then are taken the amount of air determined as a result of calculation, and if $k < 3$, so air konsumption will be calculated for conditions k =3 and the ventilator equipment will be selected accordingly with the of new consumption of air.

2. Ventilation thermal calculation

It is relatively difficult to determine the number of air needed to neutralize heat, since underground is undergoing a difficult non-stationary process, which is the result of energy exchange between massif and ventilation flows. The present work is dedicated to determining the starting values - the natural temperature and the natural characteristics of the mining masses - different rock examples. In this case, the tunnel can be presented in the form of a circled cylindrical space, in which the air is moving and exchanges by massif with mass (moisture) and energy.

The complexity of the thermal calculation also is due to with variety of heat sources - trains, passengers, escalators, transformers, etc. Besides Intensified movement is also characteristic for Tbilisi metro that cause additional difficulties in calculations. The characteristic number - "conditional intensity of movement" is determined by the formula

$$n = n_1 n_2 \geq 120, \quad (2)$$

where n is "the conditional intensity of the movement"; n_1 - number of passengers in one carriage; n_2 - number of wagons in the composition.

As the formula shows, the critical indicator of the traffic intensity "120" is possible, even if we have 3-carriage trains, but it has been suggested that there should be 5 wagons and the frequency of the motion should be at least 24 pairs in both directions [1]. In such conditions it is necessary to determine the air flow by thermal calculation.

For the proper implementation of thermal physics calculation, it is necessary to have reliable data on the current geothermal processes in the soil, thermal characteristics of the different rock and know the nature of the warm transfer on the dividing surface in the two-component thermodynamic system "Rock Massif-Ventilation Air" [2].

As noted, the heat transfer processes are always non-stationary in underground structures, from which we must distinguish the geothermic field of deposit, which can be both stationary and non-stationary. The geothermic field is stationary in relatively large depth, under the neutral layer. In massif of this layer temperature is due to the processes in the subsoil by depth, which are not characterized by seasonal variation. As it is known, with seasonal variation is characterized massif of deposit above the neutral layer, which is under the influence of solar radiation. The neutral layer always has a specific temperature and depth from the surface of the earth (Fig. 1).

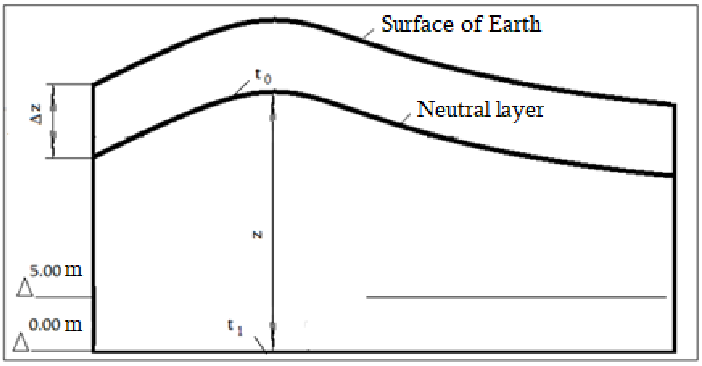

Fig. 1. Illustration of the natural layer temperature estimation of the mining array for the stationary field:
Δz - the distance of neutral layer from the earth's surface (it replicates the earth's relief), m;
t_0 - temperature of neutral layer, ℃; t_1 - temperature of mining arrayrange from the distance Z from neutral layer, ℃; 0.00, 5.00 - tunnel ground level and tunnel ceiling level

Neutral layer temperature calculated according to Tbilisi districts and is given in Table 1 and depth of neutral layer from the surface of earth - in Table 2.

Table 1 Temperature (t_0) of neutral layer for Tbilisi districts

District	Temperature, ℃	District	Temperature, ℃	District	Temperature, ℃
Avchala	12.4	Digomi	12.3	Observatory	12.7
Airport	12.3	Didube	12.6	Saburtalo	12.2
Botanical garden	12.8	Varketili	11.5	Phonichala	12.7
Gldani	12.0	Lilo	12.1	Ghrmaghele	11.9
D/Digomi	12.6	Mtawminda	10.8	-	-

Table 2 Depth of neutral layer (Δz) from the Earth's surface

District	Depth, m	District	Depth, m	District	Depth, m
Avchala	28.4	Digomi	28.0	Observatory	-
Airport	29.3	Didube	28.0	Saburtalo	28.4
Botanical garden	30.3	Varketili	28.4	Phonichala	28.3
Gldani	30.0	Lilo	30.0	Ghrmaghele	29.8
D/Digomi	28.7	Mtawminda	35.3	-	-

The natural temperature of the mining array located around the tunnel can be determined by the formula

$$t_1 = t_0 + \beta z\,, \tag{3}$$

where t_1 is a natural temperature in the mining area around the tunnel, according to the tunnel surface, ℃; t_0 - the neutral layer of the mining massif, ℃; β - geothermal gradient of this district, ℃/m; z - depth of the tunnel under the neutral layer, distance between neutral layer and tunnel ground level, m.

The distance from bottom the tunnel to the neutral layer (z) is calculated as follows: for example, it is known that the tunnel passes through the Didube district, bottom the tunnels is placement on 65 m from the earth's surface. According to Table N2, the depth of the neutral layer is 28 m, and z = 65 - 28 = 37 m.

The number of geothermal gradients in the formula (3) varies according to geographical location and depth. Its numerical value is calculated by the lowest point of Tbilisi (Didube, 428 m), according to the following formula

$$\beta = \beta_0 - 0{,}012\Delta h\,, \tag{4}$$

where β is the magnitude of the averaged geothermal gradient, ℃/m; Δh - The height of the elevation of terrain in comparison to the Didube; β_0 = 0,0357 - the number of geothermal gradient for Didube, ℃/m.

As noted above, the geothermic field is nonstationary on the of small deep (to 20 m) and in structures built on medium depth which are hypsometrically located above from the "neutral layer" and experience the seasonal variation in temperature by variation of solar radiation.

The following average indicators for Tbilisi were used to assess the temperature range of this mining massif: average temperatures of neutral layer - 12.3 ℃, the average placements depth of neutral layer from the Earth's surface – 30.0 m, average air temperature per year - 12.3 ℃. It is noteworthy that the average temperature of the neutral layer and air is the same for Tbilisi, which is explained that the snow cover in the winter and the green cover in the summer are less. Consequently, the Earth's surface is not sufficiently isolated from the direct radiation of the sun.

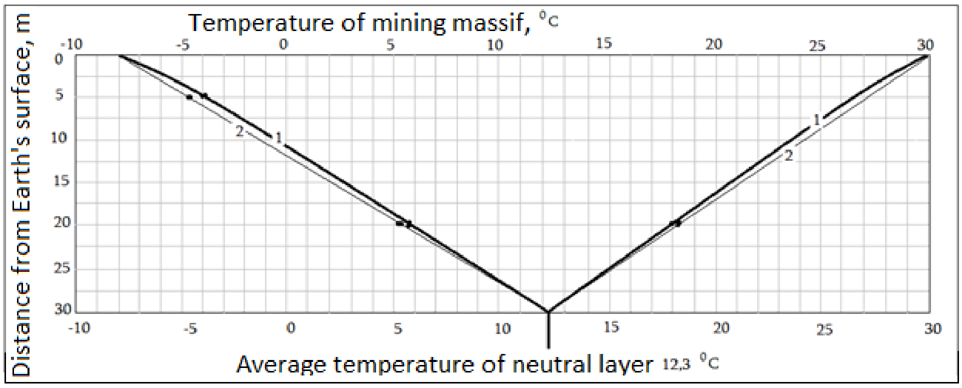

Fig. 2. Illustration of determining the natural temperature of the mining array in the conditions of non-stationary geothermal field:
1 - Experimental geothermalgram; 2 - Framed geothermal gram.

3. Thermophysical and Mass-physical characteristics of rocks

With the natural fields of temperatures and potential of mass transfer for the thermal calculation of simultaneous heat and mass (hygroscopic moisture) exchange process of underground ventilation important characteristics are also thermophysical and mass-physical coefficients of rocks (or soils) (λ, a, c, λ_m, a_m, c_m , δ_θ, γ_0), which are related to each other with a known law [3]

$$\lambda = ac\gamma_{0,} , \quad (5)$$

where λ is the heat conductivity coefficient of the rock, W/(m. K); a - coefficient of thermal diffusivity of the rock, m^2/s; c - specific heat, J/(kg. K); γ_0 - the rock density, kg/m^3.

Mass-physical characteristics of rocks are related to each other by analogical formulation, thus confirming the analogy of these processes [4]

$$\lambda_m = a_m \; c_m \; \gamma_0 , \quad (6)$$

where λ_m denoting mass conductivity factor of the rock, kg.mol/(J.m.s); a_m – the mass transfer potential diffusivity factor for the rock, m^2/s; c_m - the isothermal factor of specific mass for the rock, mol/J.

It is noteworthy that the same dimension of coefficients is a manifestation of the threefold analogy and shows how responds to the impact of impulse heat or mass on the any field by changing of the appropriate potential of transfer into field.

Thermophysical characteristics of the rocks spread across the tunnels of the deep submergence of Tbilisi metro are given in Table 3.

In the table 3: γ_0 - the rock density, kg/m^3; a*10^8 - coefficient of thermal diffusivity of the rock, m^2/s; c - specific heat, kJ/(kg. K); λ - the heat conductivity coefficient of the rock, W/(m. K).

Table 3 Thermophysical characteristics of the rocks

N	Characterization of the rock	Porosity, %	γ_0, kg/m^3	a, m^2/s	c, J/(kg. K)	λ, W/(m.K)
1	Finely pale lime sandstone (light gray)	9.26	2700	98.85	837	2.234
2	Clayey Alevolite, Slightly Sidetiting (Gray)	14.04	2650	62.33	983	1.810
3	Medium grained sandstone (light gray)	18.21	2800	86.83	867	2.085

The mass-physical characteristics of the rocks have been studied for different temperatures. Its four significances are selected (275, 289, 303 and 323 K) to include possible geothermal conditions for any underground structures. For all samples were made sorption and desorption isotherms in water vapor for all four temperatures.

In the case of ventilation of tunnels, the binary system "mining massif - ventilation flow" thermal conduction is not only under the influence of the temperature gradient but also of the gradient of mass transfer potential. The ultimate thermal flow consists of two elements: one is caused by the temperature gradient and the second mass transfer potential gradient. Similarly, the mass flow consists of two elements. In this case the direct driving force is a gradient of mass transfer potential, and the mass additions flow originates to the temperature gradient. This is reflected in the mathematical expression of the principle of Onsager reciprocity [5] that express the equality of certain ratios between flows and forces in thermodynamic systems out of equilibrium, but where a notion of local equilibrium exists

$$J_i = \sum_{k=1}^{n} L_{ik} X_{k(i=1,2,\ldots,n)}\,, \tag{7}$$

where J_i is thermodynamic driving forces (temperature and mass transfer potential) that generated both flows; $L_{i,k}$ - the physical environment in which energy or substance is transmitted (in our case thermophysical and Mass-physical characteristics of rocks); X_k - potential gradients that originated streams.

For the thermodynamic driving force, such are the thermodynamic temperature gradient and the gradient of mass transfer, the principle of Onsager's reciprocity has a form

$$J_1 = L_{11}X_1 + L_{12}X_2\,, \tag{8}$$

$$J_2 = L_{21}X_1 + L_{22}X_2\,, \tag{9}$$

where J_1 is a thermal flow density, which is determined by the Fourier law in a private case; J_2 - the mass flow density, which is determined by the Fick's law or Luykov law, in the private case, what is the power of the forces X_2, the gradient of concentration, or the mass transfer gradient. In a continuous transmission in a continuous medium, where are no pores and mass transfer is impossible, $X_2 = 0$ and from formula (8) we have to do with the Fourier law

$$q = -\lambda gradT, \tag{10}$$

where $J_1 = q$ is a thermal flow density, J/(m^2.s). Thus, during the thermal conductivity, the physical parameter L_{11} from formula (8) is the heat conductivity coefficient λ. Similarly, during the isothermal mass transfer in the capillary-porous body, when the temperature gradient is equal to zero $X_1 = 0$, and from formula (9) is obtained Luykov law of mass transfer

$$q_m = -\lambda_m grad\theta, \tag{11}$$

where $J_2 = q_m$ is the mass flow density, kg.mol/(J.m^2.s); $grad\theta$ - the gradient of potential of mass transfer, J/(mol.m).
By formula (6), the formula (11) will get the following look

$$q_m = -a_m c_m \gamma_0 grad\theta. \tag{12}$$

4. Determination of the mass transfer potential diffusivity factor (a_m) for the rock

Formulas (9) and (12) indicate that for determining of the coefficient a_m is necessary the protection of the isothermal mass transfer process in a special laboratory device - isothermal container.
For the purpose of solving the set tasks, the samples were pre-hydrated and then molded in the cylindrical containers together with a completely dry filter paper. The time for observation of containers at temperatures 275, 289, 303 and 323 K is 48 hours.
During this time, the thermodynamic equilibrium will be established in the boundary layer of the mentioned bodies. Then we put the boundary layers of both bodies in the glass bouquets and their mass would be analyzed. In order to control the results, observations were conducted on three containers at the same time, and parallel samples from each container would be taken. Thus, each size of the coefficient is actually the average size of six measurements.
With the help of the parameters and computational values obtained by the experiment, the coefficient mass transmission potential conductivity factor will be defined with the following formula

$$a_m = \frac{\pi}{\tau}\left[\frac{\Delta M}{2S\gamma_0(U_0 - U_1)}\right], \tag{13}$$

where ΔM is a mass difference of sample before and after testing, kg; S - Container area, m^2; γ_0 - Density of absolutely dry sample, kg/m^3; U_0 - initial sample moisture, kg/kg; U_1 - moisture content of sample in the border zone, kg/kg.

The numerical values of the mass transfer potential diffusivity factor for the rock (a_m) identified by the experiments are given in Table 4.

5. Determination of the isothermal factor of specific mass (c_m)

In laboratory conditions, by means of the known methods have been constructed isotherms $U = f(\varphi)_T$ of sorption and desorption for four temperatures: 275, 289, 303, 323 K (Fig. 3).

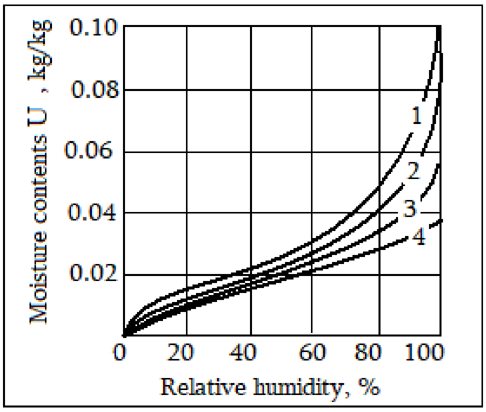

Fig. 3. Isotherms of sorption of sample of rock with water vapor at the temperatures, *K*: 1 - 275, 2 - 289, 3 - 303, 4 – 323.

After that mas determined mass transfer potential by formula

$$\vartheta = RT \ln \varphi , \qquad (14)$$

where ϑ is a mass transfer potential (chemical potential with the sign minus), J/mol; R - Universal constant of gas, J/(mol.K), R = 8,3144; T - Absolute temperature of ventilation flow, K; φ - Relative humidity of the ventilation stream, in parts of one, i.e. $0 \leq \varphi \leq 1$.

On the basis of the results were constructed curves $U = f(\varphi)_T$, and the potential of mass transfer was calculated using the formula

$$\theta_0 = R(273 + t_0) \ln u_0 / u_{\max} , \qquad (15)$$

where (273+t_0) is temperature of rocks sample; u_0 - initial or natural moisture content of rocks sample; $u_{\max}$ - maximal sorption moisture content of rocks sample.

By potential of mass transfer calculated according to formula (15) were constructed curves u u= $f(u)_T$ presented in Fig. 4.

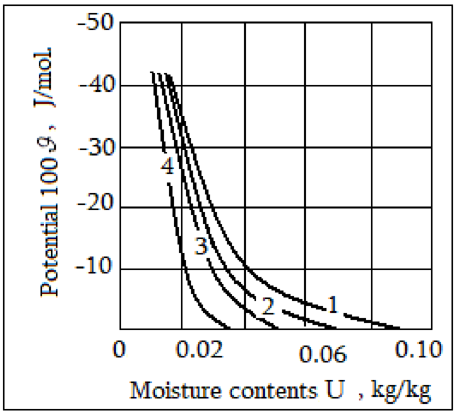

Fig. 4. Changing of mass transfer potential $\theta_0 = R(273 + t_0)\ln u_0 / u_{\max}$ in according of moisture content of rocks sample at the temperatures, *K*: 1 - 275, 2 - 289, 3 - 303, 4 – 323.

By the method of graphic differentiation from the latter isotherm has been determined the isothermic mass capacity coefficient.

The isothermic mass (moisture) capacity coefficient is the amount of the mass which at one kilogram of absolutely dry part of the sorbent, gives potential of mass transfer equal to the value an one J/mol. The isothermic mass (moisture) capacity coefficient is determined from the ratio

$$c_m = (\partial u / \partial \theta) . \qquad (16)$$

It should be noted that tangent of angle between tangent of the curve $\theta = f\,(\mathrm{u})_T$ and to the abscess is equal to the number of c_m .

The numerical values of the isothermal factor of specific mass for the rock (c_m) identified by the experiments are given in Table 4. The numerical values of the conductivity factor of mass (λ_m), also included in Table 4, are calculated by the formula (6).

During the constant of temperature, the isothermal factor of specific mass for the rock (c_m) has straight proportion relations with a potential of mass transfer. Similarly, with a relative humidity of equilibrium air as well as with the sorption mass content this coefficient has also straight proportion. During the constant of mass transfer potential, in according to the temperature changings, coefficient has inverse proportion relation, which agrees with the theoretical implications that increasing of the temperature originates the reduction of Van der Waals forces.

With the thermodynamic potential c_m coefficient has an inverse proportion attitude, which determines by the structure of the calculation formula ($\mu = RT \ln \varphi$). If this fact did not contain a theoretical discrepancy, then it would be impossible to justify what direction should be proportionality between coefficient c_m and mass transfer potential μ .

The matter is that, according to modern ideas, the temperature increase leads the reduction of Van der Waals forces in the field of sorption forces, the result of which is reduced of coefficient c_m. In this case the power of sorption field and the characteristic size of this field, the potential of mass transfer, must be reduced. Consequently, between the couples θ, T and c_m, T should be inversely proportion dependence, and the relationship between the two - θ and c_m should be a direct proportionate attitude. This circumstance does not contain any contradictions between to theoretical ideas and experimental results of determining the coefficient of isothermal specific mass. Therefore, this work is using potential of mass transfer with the sign minus, defined by the formula (14).

As is known, the temperature gradient in the capillary-porous body produces an additional gradient of mass transfer, that is called as thermogradient mass transfer or effect of Soret. In the isothermal conditions, the effect of the Soret is equal to zero, that shows the main law of Luikov, defined by the formula (11) and mass transfer is performed only by means of potential of mass transfer.

According to modern ideas, the basic law of non-isothermal mass transfer has the form

$$j_m = -\lambda_m (\nabla\theta + \delta_\theta \nabla T). \qquad (17)$$

As shown by the formula (17), the thermogradient coefficient determines the additional increase caused by the temperature gradient, which is the size of the number $\delta_\theta \nabla T$. If the mass flow density $j_m = 0$, then this formula gives

$$\delta_\theta = (\nabla\theta / \nabla T)_{j_{m=0}} \approx \left(\frac{\nabla\theta}{\nabla T}\right)_{j_{m=0}}. \qquad (18)$$

According to the sorption isotherms, are constructed the new curves $\theta = f(T)_{j_{m==0}}$, from which the numerical quantities of thermogradient coefficient were defined for the rocks (or soil) that are listed in the table 4.

Table 4. Mass-physical characteristics of the rocks

γ_0	u	$a_m \cdot 10^{-9}$	$c_m \cdot 10^{-5}$	$\lambda_m \cdot 10^{-10}$	$\delta_\theta \cdot 10^{-2}$
1	2	3	4	5	6
Temperature T=275 K					
2700	0,01	2,28	0,38	0,23	1,03
	0,02	1,60	0,70	0.30	1,89
	0,03	1,04	1,47	0,41	3,97
	0,04	0,72	2,68	0,52	7,24
	0,05	0,61	4,56	0,75	12,3
	0,06	0,58	7,20	1,13	19,4
	0,07	0,55	10,45	1,57	28,2
	0.08	0,55	14,20	2,13	38,3
2650	0,01	2,10	0,30	0,16	0,81
	0,02	1,5	0,80	0,32	2,16
	0,03	1,27	1,75	0,39	4,72
	0,04	1,39	3,60	1,08	9,72
	0,05	1,05	7,00	1,96	18,9
	0,06	1,00	12,8	3,39	-
	0,07	0,94	22,0	5,50	59,4
	0.08	0,95	-	9,09	-

γ_0	u	$a_m .10^{-9}$	$c_m .10^{-5}$	$\lambda_m .10^{-10}$	$\delta_\theta .10^{-2}$
1	2	3	4	5	6
2800	0,01	1,61	0,4	0,18	1,08
	0,02	0,97	1,00	0,27	2,70
	0,03	0,75	2,55	0,54	6,88
	0,04	0,67	5,50	0,99	14,81
	0,05	0,62	9,60	1,68	25,90
	0,06	0,60	15,3	2,59	41,37
	0,07	0,58	22,5	3,67	60,72
	0.08	0,55	30,2	4,69	81,53
Temperature T=289 K					
2700	0,01	4,83	0,35	0,45	0,95
	0,02	3,61	0,55	_	1,49
	0,03	2,69	1,50	1,09	4,10
	0,04	2,05	3,55	1,96	9,58
	0,05	1,67	6,80	3,14	16,41
	0,06	1,39	11,0	4,12	29,84
	0,07	1,27	15,85	5,28	_
	0.08	1,17	19,80	6,24	53,55
1	**2**	**3**	**4**	**5**	**6**
2650	0,01	3,89	0,55	0,57	1,48
	0,02	3,62	0,62	0,60	1,67
	0,03	3,33	0,92	0,83	2,48
	0,04	3,00	1,40	1,12	3,78
	0,05	2,60	2,05	1,43	5,53
	0,06	2,17	2,90	1,88	7,83
	0,07	1,78	4,05	1,93	10,94
	0.08	1,5	6,25	2,51	16,87
2800	0,01	5,69	0,30	0,48	0,81
	0,02	3,28	0,88	0,73	2,37
	0,03	2,19	2,35	1,44	6,34
	0,04	1,82	4,95	2,52	13,41
	0,05	1,55	9,20	4,01	24,84
	0,06	1,36	14,95	5,51	39,01
	0,07	1,19	20,50	6,86	55,32
	0.08	1,06	41,00	-	-
Temperature T=303 K					
2700	0,01	9,71	0,28	0,62	0,76
	0,02	6,14	0,55	0,91	1,48
	0,03	4,44	1,48	1,78	4,00
	0,04	3,44	2,97	2,76	8,02
	0,05	2,86	4,87	3,37	12,61
	0,06	2,50	7,50	5,06	20,32
	0,07	2,22	_	_	_
2650	0,01	8,80	0,25	0,58	0,67
	0,02	6,55	0,68	1,18	1,84
	0,03	4,94	2,20	3,83	5,94
	0,04	4,06	7,00	7,52	18,92
	0,05	3,56	_	_	_
	0,06	3,22	_	_	_
	0,07	3,03	_	_	_
	0,01	8,39	0,30	0,70	0,81
	0,02	5,44	0,90	1,37	2,43

γ_0	u	a_m .10[-9]	c_m .10[-5]	λ_m .10[-10]	δ_θ .10[-2]
1	2	3	4	5	6
2800	0,03 0,04 0,05 0,06 0,07 0.08	4,00 3,36 2,92 2,50 2,19 1,92	2,48 5,06 8,96 13,85 20,00 22,98	2,78 4,76 7,31 9,69 - -	2,69 13,66 24,19 37,74 54,00 -_

Table 5 Physical coefficients

Name	Designation	dimension
Density (rock, soil)	γ_0	kg/m^3
Heat conductivity (rock, soil)	λ	W/(m. K)
Specific heat (rock, soil)	c	J/(kg. K)
Thermal diffusivity (rock, soil)	a	m^2/s
Mass conductivity (rock, soil)	λ_m	kg.mol/(J.m.s)
Mass transfer potential diffusivity (rock, soil)	a_m	m^2/s
Isothermal factor of specific mass (rock, soil)	c_m	mol/J
Initial sample moisture	U_0	kg/kg
Moisture content of sample in the border zone	U_1	kg/kg
Universal constant of gas - R = 8,3144	R	J/(mol. K)

Conclusions

- The geothermic field of mining massif is stationary for stations and tunnels located under the neutral layer, which is due to the processes in the subsoil, but in structures built on small or medium depth which are hypsometrically located above from the "neutral layer" this fields are non-stationaries and temperature of the massive is experiencing seasonal variation by the influence of solar radiation.
- Based on the presented material, it is possible to determine the dates that are necessary for thermal calculation of underground ventilation - the natural temperatures of massif for any period of the year for underground deployments located deep, as well as located relatively less in depth.
- The results of the study show that in the isothermal conditions, the mass transfer potential diffusivity factor for the rock has inverse proportion dependency on the density and moisture indicators. Similarly, with temperatures increasing by constant moisture contents causes to a significant increasing of a_m .
- During the constant of temperature, the isothermal factor of specific mass for the rock
(c_m) has straight proportion relations with a potential of mass transfer. Similarly, with a relative humidity of equilibrium air as well as with the sorption mass content

this coefficient has also straight proportion. During the constant of mass transfer potential, in according to the temperature changings, coefficient has inverse proportion relation, which agrees with the theoretical implications that increasing of the temperature originates the reduction of Van der Waals forces.

- By means of the presented results can perform thermal physics calculations of underground structures.

This work was supported by Shota Rustaveli National Science Foundation (SRNSF) [Grant number 216068, Project Title “Prevention methods development against aerosol terrorism for ventilation of Tbilisi subway”]

References

[1] В.Я. Цодиков. Вентиляция и теплоснабжение метрополитенов. Москва, Недра, 1975, 566 с.

[2] Ш.И. Ониани, О.А. Ланчава. Методика прогнозирования температурного режима шахт в осложненных условиях. В кн.: Единая методика прогнозирования температурных условий в угольных шахтах. Макеевка-Донбасс, 1979. с. 75-92.

[3] А.А.Дзидзигури, Ш.И.Ониани, Г.В.Дуганов и др. Теплофизические свойства горных пород и методы их определения. Тбилиси, Мецниереба, 1966, 228 с.

[4] O. Lanchava. Higroscopic mass- and thermal Exchange in underground structures. Tbilisi, GTU, 271 p., 1999.

[5] L. Onsager. Reciprocal Relations in Irreversible Processes. I., Phys. Rev. 37. 405-426, 1931.