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ANALYSIS OF HEAT LOSSES IN UNDERGROUND TUNNELS FOR PREHEATING OF VENTILATION AIR

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ABSTRACT

Methods for calculation of thermal conditions and heat loss parameter for an underground tunnel into surrounding sub-soil were developed in the first half and in the middle of the 20th century [18-20], when the study of complex heat- and mass exchange processes between underground tunnel, sub-soil and outdoor air was started. In a tunnel it is important to meet specific microclimate parameters such as air temperature and temperature surfaces of the protecting designs in order to reach thermal comfort. In that regard it is necessary to use climate control system, which in turn increases the capital expenditure. The article is based on analysis of the existing methods of heat loss in the underground tunnel. The complexity of the calculations is in the fact that there is soil of varying thickness between the underground tunnel and ambient air, which causes the attenuation of outdoor temperature variations. This heat transfer process is associated with a large thermal massiveness of soil layers, which absorb warmth.

Keywords: heat loses, ventilation, heating, tunnel.

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1. INTRODUCTION

At present time, the development of engineering communications (electricity, heat and water supply systems, communication networks) [1], the industrialization and urbanization fatally lead to deficit of placement area for engineering utilities in big cities [2].

To solve this problem, communications are located in a specialized underground tunnel, providing the possibility of maintenance and operation of the systems in it.

Network of underground communication tunnel is developing dynamically. It requires more accuracy in terms of providing normative microclimate conditions influenced on durability and technical characteristics of communication utilities [3]. The scheme of an underground tunnel is shown on Fig. 1, 2.

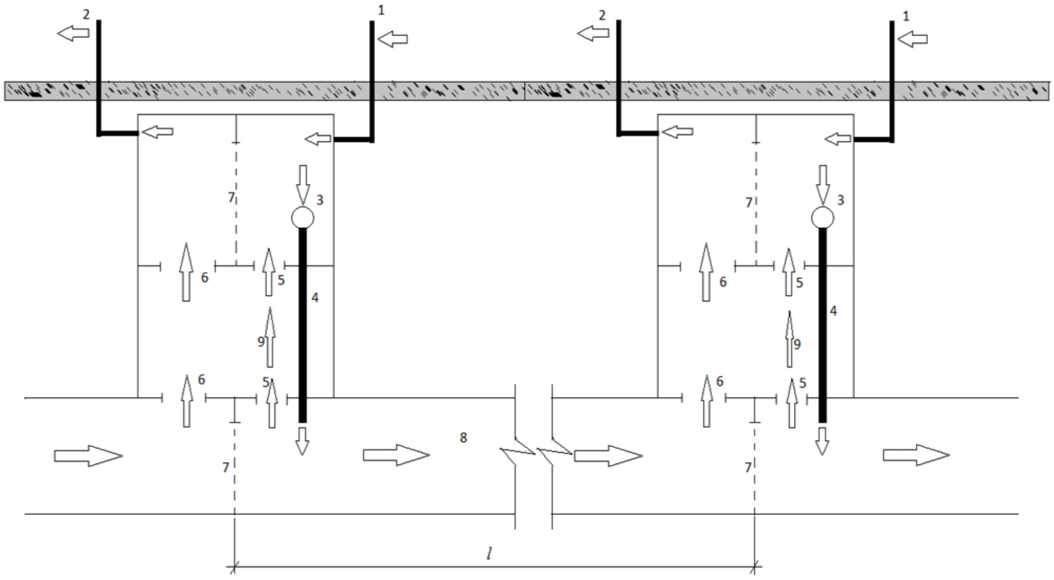

Figure 1 The scheme of an underground tunnel, where 1 – inlet duct, 2 – exhaust duct, 3 - fan, 4 - air duct, 5 – openings for natural ventilation with a ladder for the service staff, 6 – technological aperture for exhaust air, 7 - door, 8 – collector, collector site l-length, 9 – recirculation contour.

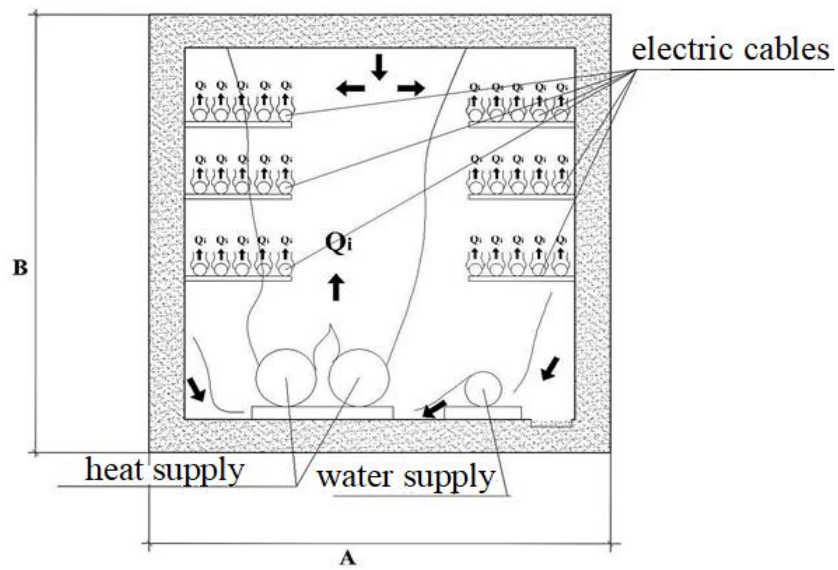

Figure 2 The scheme of an arrangement of communications in a tunnel. Q - thermal streams from heat supply and electric cables, A и B - the tunnel sizes.

One of the key factors affecting tunnel microclimate is heat loss parameter. The placement depth of underground tunnel may vary. Also heat emissions from communications with different intensity take place. Thus, the heat losses along the length of the tunnel may be variable. And also, the heat losses of the tunnel may be variable, depending on the time of a year.

2. METHODS OF CALCULATING THE THERMAL CONDITIONS

Temperature of external air changes in time and it differs from air temperature in a tunnel. If air temperature is higher than the earth less than an air temperature in a tunnel, thermal losses are formed. Massiveness of the soil surrounding a tunnel leads to a delay of change of temperature in a tunnel. Temperature in a tunnel in a cold season is higher than air temperature over the earth, and in warm time air temperature in a tunnel is lower than air temperature over the earth. Therefore in a warm season warmth from external air comes to soil and over time reaches a tunnel. And in a cold season the return process takes place. Only in initial part of a tunnel air temperature is close to external temperature because of work of system of ventilation and then air temperature in a tunnel changes coming nearer to the average temperature of the surrounding collector of soil. It is known that in soil at a depth soil temperature practically ceases to change at a depth more than 3 meters therefore the decision on carrying out calculations of thermal losses of the tunnel buried on depth to 10 meters, for the analysis and understanding of the conducted research was made. [4].

To apply the method of Kazantsev B.A. [20] for calculation of sub-soil temperature around the tunnel depending on required depth of tunnel placement, taking into account such parameters as heat loss period, sub-soil heat diffusivity, range of temperature variation [5] at sub-soil surface is necessary. When applying the Kazentsev B.A. [20] method for calculation of sub-soil temperature around the tunnel depending on required depth of tunnel placement, it’s necessary to take into account the heat loss period, sub-soil heat diffusivity and range of temperature variation [5] at sub-soil surface. It is realized by the method of Vlasov O.E. [18]. Vlasov O. E. was studying problems of impact of buildings thermal stability on set parameters of a microclimate, especially temperature of internal air and surfaces of building envelope. At this time, computer modeling was not developed, so he used simple engineering formulas.

For determination of calculated value of surface area for envelop tunnel in tunnels with rectangular cross-section, it is important to take into account the influence of corners in tunnel, which increases its heat loss values compared to circular tunnel. It is achieved by addition to each inner geometrical size of tunnel of some parameter that takes account the following parameters: heat loss period, heat conductivity and heat capacity as well as density of material for envelop the tunnel.

Heat-transfer coefficient is determined with the equation (1) [19].

$$k = \frac{1}{\frac{1}{\alpha_{\text{в}}} + \frac{2 \cdot H + \sqrt{z \cdot \frac{\lambda}{\rho \cdot c}}}{3 \cdot \lambda_S}}, [W/(m^2 \cdot °\text{C})] \quad (1)$$

H distance between ground-level and top of bridging measured, m

λ heat conductivity coefficient of envelop structure of tunnel, W/(m·°C)

λ_s heat conductivity coefficient of sub-soil, W/(m·°C)

ρ is density of material for envelop structure in tunnel, kg/m^3

c heat capacity of tunnel envelop structure measured, kJ/ (kg·°C)

$\alpha_{\text{в}}$ coefficient of heat transfer on the surface, W/(m^2·°C)

z time, s

Thermal losses can be calculated on a formula (2)

$Q = k \cdot (t_{tunnel} - t_{ext}) \cdot F$ (2)

K Heat-transfer coefficient, W/(m^{2}·°C)

t_{tunnel} air temperature in a tunnel, °C

t_{ext} air temperature is higher than the earth, °C

F surface area of the protecting tunnel designs, m

Calculations of thermal losses for climatic conditions of the city of Moscow are carried out. On the basis of this method, for underground tunnel with rectangular cross-section 4.83m^2, placement depth up to 10 m and embedment width – 1 m, heat conductivity coefficient for clay loam sub-soil around the tunnel – 1.18 and 1.26 W/(m2·°C) for dry sub-soil and frozen sub-soil, respectively, with constant air temperature in tunnel + 30 °C, [11]. Cooling of tunnels isn't provided with norms of the Russian Federation in a hot season which is connected with ability of engineering networks to maintain surrounding temperature of 50 degrees and more.

3. RESULTS OF CALCULATIONS

The scheme of cross section of a tunnel is shown in fig. 3

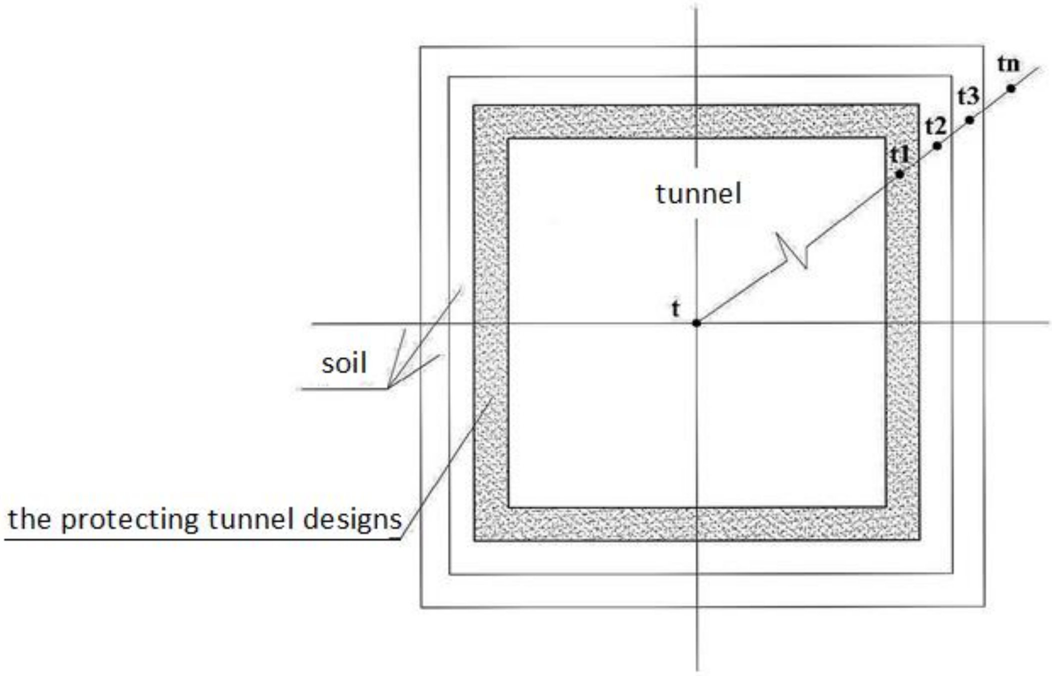

Figure 3 Scheme of cross section of a tunnel. t - air temperature in a tunnel, t_1, t_2, t_3, t_n - temperatures of layers of earth surrounding a tunnel.

The results obtained are shown in Fig. 4 and 5.

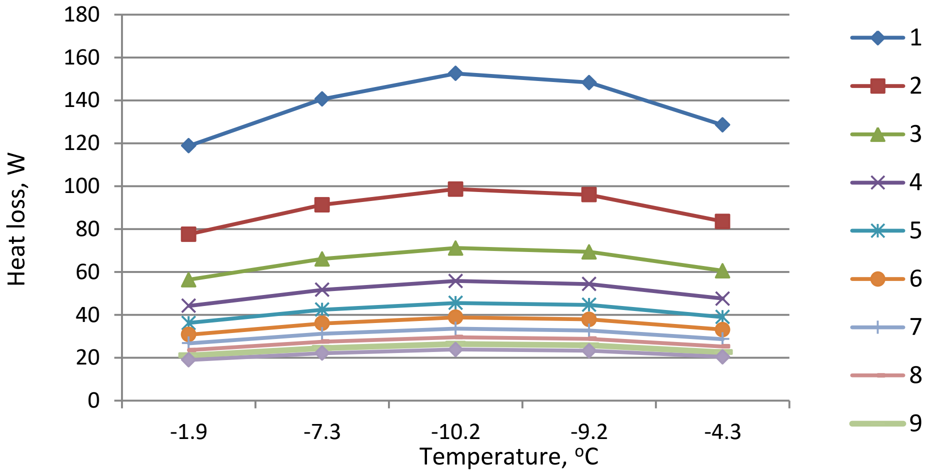

Figure 4 Variation of heat loss parameter for underground tunnel into sub-soil during cold period depending on outdoor air temperature. On axis X average temperatures of external air for the city of Moscow in months November, December, January, February and March are postponed. Schedules 1-8 show how thermal losses would change if the tunnel would be located at a depth from 1 m to 8 m, with growth of depth by 1 m.

Fig. 4 and 5 demonstrate that the heat loss values are reduced with increasing of tunnel placement depth as well as season variation of outdoor air temperature. However, Kazantsev B.A. calculation method doesn't take into account shape and size of constructions as well as thermal characteristics of surround sub-soil and indoor space heating time period. But it is necessary especially if there is a heating system in a tunnel. This method is suitable only for tunnels placed at depth up to 10 m. Also humidity of envelop structures is varied with time and effects on tunnel heat loss parameter. The value of humidity is difficult to register with this method.

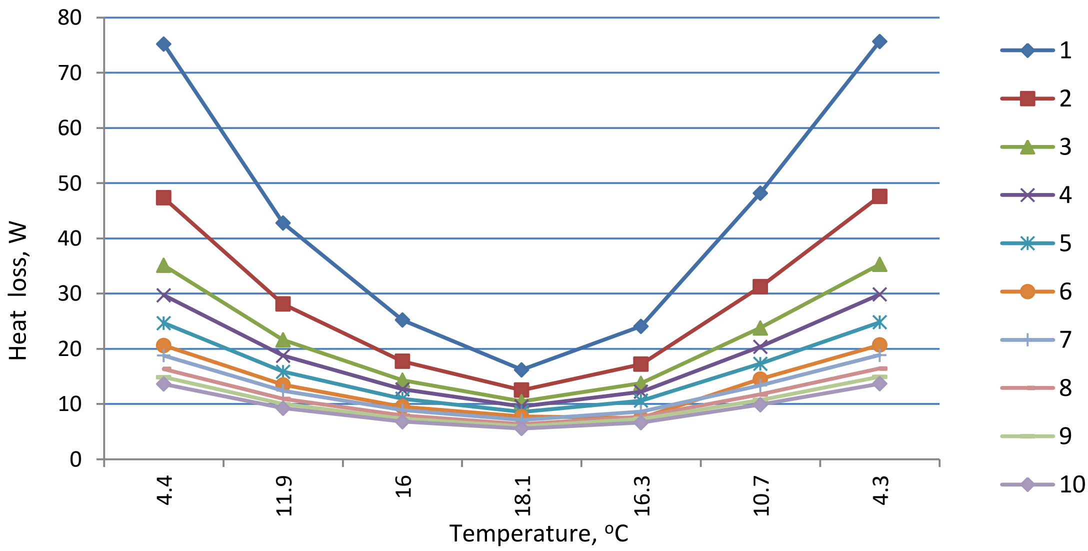

Figure 5 Variation of heat loss parameter for underground tunnel into sub-soil during warm period depending on outdoor air temperature. On axis X average temperatures of external air for the city of Moscow in months April, May, June, July, August, September, October are postponed. Schedules 1-8 show as thermal losses would change if the tunnel would be located at a depth from 1 m to 8 m, with growth of depth by 1 m.

Introduction of air movement in tunnel with varied inner air temperature and heat loss parameter in the above methods was not accomplished [6, 7, 8].

Calculation of heat loss parameter for communication tunnel into surround sub-soil by prof. Machinsky V.D.'s method is considered. In this case, a heat loss parameter is calculated for floor slab, wall and floor separately [4, 9].

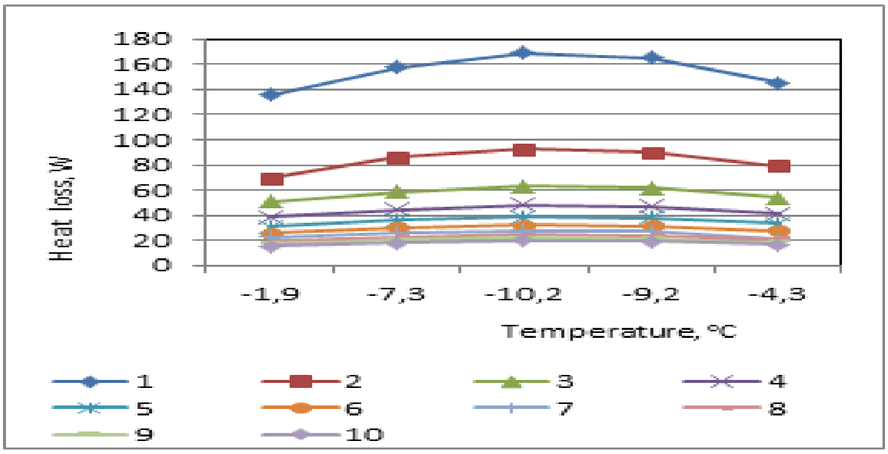

Figure 6 Variation of heat loss parameter for underground communication tunnel into sub-soil during cold period depending on outdoor air temperature as well as a replacement depth of tunnel, 1-10 the tunnel depth in m. On axis X average temperatures of external air for the city of Moscow in months November, December, January, February and March are postponed. Schedules 1-8 show as thermal losses would change if the tunnel would be located at a depth from 1 m to 8 m, with growth of depth by 1 m.

On the base of results of calculation, the diagrams of the effect of monthly average air temperature in cold period on heat loss parameter of underground tunnel taking into account different tunnel placement depth are obtained (Fig. 6, 7).

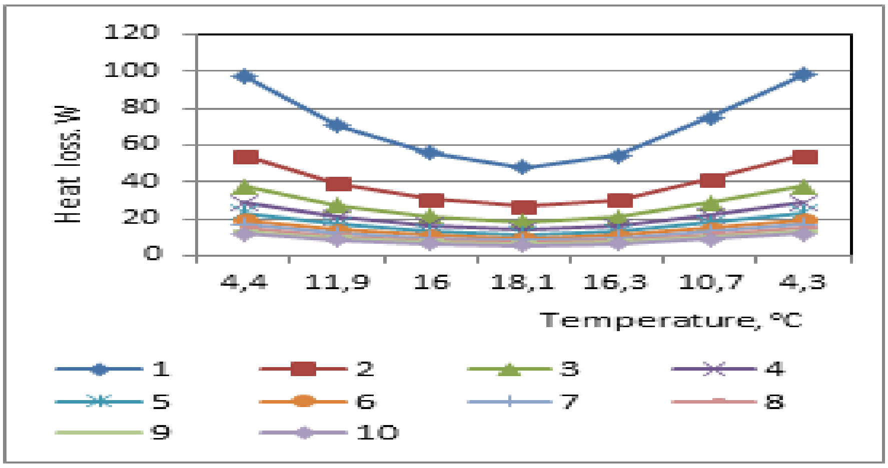

Figure 7 Variation of heat loss parameter for underground communication tunnel into sub-soil during warm period depending on outdoor air temperature as well as placement depth of tunnel, 1-10 the tunnel depth in m. On axis X average temperatures of external air for the city of Moscow in months April, May, June, July, August, September, October are postponed. Schedules 1-8 show as thermal losses would change if the tunnel would be located at a depth from 1 m to 8 m, with growth of depth by 1 m.

The Choice of design temperature for heat loss through sub-soil layer depends on sub-soil mass with varied width and thermal properties that is not taken account in this method.

Analysis of V.D. Machinsky's method and the method developed in Teploelectroproect Institute.

The method developed in Teploelectroproect Institute takes into account climate condition of construction region, ambient sub-soil temperature on the level of tunnel position, as well as the shape of tunnel cross-section but depth of tunnel placement relatively the ground level as well as sub-soil heat conductivity coefficient. V.D. Machinsky's method takes into account tunnel shape and sub-soil characteristics depending on tunnel placement depth but climate conditions.

The calculation of heat loss parameter, other factors being equal, are realized and shown in Fig 8.

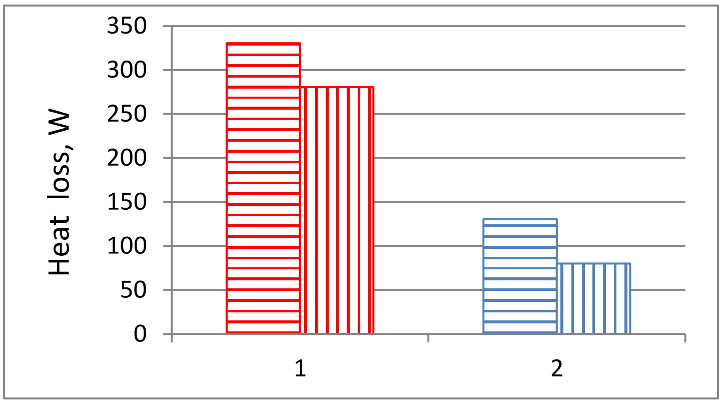

Figure 8 Heat loss into sub-soil mass in cold period (1) warm period (2), horizontal hatching – according to method of Teploelectroproect Institute, vertical hatching – by V.D. Machinsky's method

The differences between the calculation results for the both methods are within 15 %.

4. DISCUSSION

The calculations allow to plot dependency graphs of heat underground communication collector from the mean monthly temperature of outside air during the cold period of the year, taking into account the different level of foundations. Choosing a design temperature for calculations of heat losses through the thickness of the soil in the outside air is dependent on the massiveness of the soil. The deeper is the collector, the more massive ground surrounding the tunnel is. As depth increases, the inertia of the temperature changes of soil and indoor air in the manifold does as well, and the amplitude of the fluctuations in temperature fades with increasing intensity. Soil temperature with increasing depth depends on the average outdoor temperature for periods of time from days to a year or more. The rugged ground in terms of the problem varies from 8 at a depth of 1 m to 80 at a depth of 10 m. With a depth of reduced heat loss and their change over time is flattened, approaching stationary mind.

During the cold period of the year, heat loss through an array of soil underground communication collector on falling one meter lower than two meter that is due to the fact that the collector located at a depth of one meter gives warmth directly into the frozen ground, and then to the outside air. Collector at the depth of 2 meters gives warmth to dry (not to freeze) to the soil, and he in turn frozen. The sequence of the heat transfer from the collector, recessed at 2 meters ground array, as follows: from the internal air through the tunnel envelope design collector to dry (not frozen) ground at a depth of 2 m, then through dry soil to frozen the ground with freezing temperatures in the range from 0 to -2°C, then through the frozen ground in the environment. Difficult spot for calculation heat loss is a transition zone from dry ground to the ground state frozen, as its size and location in the ground change over time. As resistance to heat dry layer of soil and very little difference between the freezing point of water in the pores of the soil and the internal air temperature in the collector is great, the loss of heat at a depth of 2 meters will be higher than at a depth of 1 meter. When further falling, collector heat loss will decrease because the growing resistance to heat dry soil.

The calculations and graphs can be considered valid if exclude influence of soil freezing zone offset through revenue from the underground heat collector and read depth frozen a ground and temperature of freezing of water in the pores of the soil is constant and equal to the average for the duration of the cold period.

Reviewed the methodology to calculate the heat loss into the ground with the error that is associated with a number of assumptions described above, to allow the use of this technique as a trial for the rough analysis of underground communication collector heat loss in cold period of the year.

5. CONCLUSION

Heat balance is a dominant factor when required microclimate formation in underground tunnel [12]. Available methods for calculation of unsteady heat losses by underground tunnels take into account such factors as depth of underground tunnel placement, and shape, as well as sub-soil properties etc. [13, 14, 15] with different limitations. One of the problems of the methods is inability of determination of time period shift of maximal/minimal temperature variations and heat losses by underground tunnel relatively outdoor air temperature varied with time including the building dimensions [16, 17]. It makes difficult to control of equipment operation [21]. In the above methods, the air movement in tunnel effecting on inner air temperature and heat losses is not taken into account.

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