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Modeling of Aeration of Buildings and Facilities Erected in a Mountain Valley

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Abstract. The article considers an acute ecological and social situation of mountainous regions determining the complex study of "Mountain-city-man". When analyzing urban planning on a complex terrain, it becomes clear that there is a certain gap in a field of horticultural research in special extreme hot-calm climatic conditions. Orographic features of the relief cause the presence of a local winds system, from which the most pronounced are slopes and mountain-valleys. The compiled mathematical model of slope winds allows predicting aerodynamic characteristics of natural ventilation of buildings and facilities erected in the mountain-hollow space. The proposed calculation technique can be widely used in construction practice and allow to determine the aerodynamic characteristics of the building, aerodynamic coefficients, wind loads, air exchange between the room and the external environment, heat input through the infiltration of air through the enclosing structures.

1. Introduction.

In the modern world - more and more attention is paid to the issues of rational land use, taking into account the maximum conservation of their natural uniqueness.

The researchers are faced with the problem of further study of special conditions of mountain relief with complex natural and climatic conditions for urban development.

It is noted that by now a large volume of research has been done and practical recommendations have been developed for improving the microclimate, reducing dust and gas content in flat areas [1,2,3,4,5,6,7,8,9].

Many international organizations are involved in mountainous topics, urban development aspects of mountain areas have been studied by a number of research institutes and by a number of domestic foreign scientists [10,11,12,13,14,15,16].

An analysis of the development of urban development on a complex terrain requires further research, characterizing the microclimatic and ecoclimatic conditions of urban development, erected in areas with complex mountainous terrain, which was not given due attention.

2. The formulation and method of solving the optimization problem.

The purpose of this article is to study the aerodynamics of buildings and facilities erected in a mountain basin, choice of rational schemes and methods for natural ventilation of a complex relief, taking into account the role of insolation and thermal regimes in the natural air exchange of urban buildings built in the mountain-hollow space.

The complex relief of the mountain basin, being a characteristic form of the relief space, is considered as a calm or slightly winded climate condition in which the aeration of the city and

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buildings occurs due to the ascending anabatic warm air and the night of the katabatic cool air descending. In this connection the planning structure of the settlement should be developed taking into account this wind factor as a mechanism for improving the environment.

The mountain hollow, representing a cup-like depression closed from all sides, is the worst in terms of aerodynamic characteristics in comparison with mountain valleys, because the architectural and construction practice of developing the mountain-hollow space shows that as the depth of the excavation increases, the heat-wind regime, dispersion and spread of dust, gas and other anthropogenic emissions are getting worse.

The calculation scheme for the development of anabatic and katabatic winds of the slopes of the mountain-hollow space is shown on Fig. 1, 2.

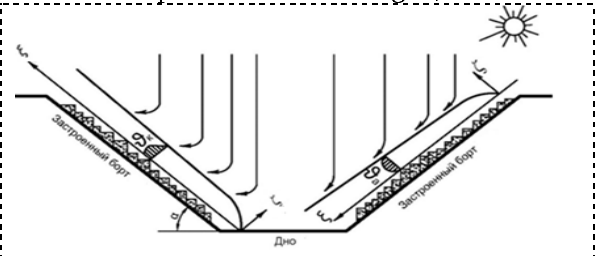

Fig. 1. Calculation scheme for the formation of anabatic and katabatic winds in the mountain-hollow space

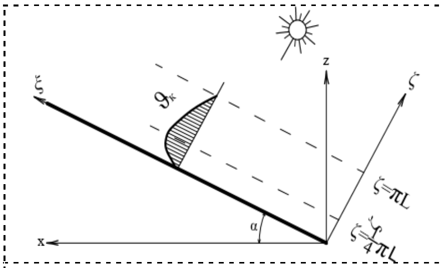

Fig. 2. Calculation scheme of winds of the slope

The features of the mountain hollow space geometry is estimated by the magnitude of the relative depth of the mountain hollow

$$P = \frac{H}{\sqrt{L_1 L_2}}, \quad (1)$$

where H - the depth of the hollow, m; L_1 и L_2 - the length and width of the mountain hollow in the plan, m. When P<0,15 - shallow mountain valleys. When 0,15 < P <0,3 - medium one; P>0,3 – deep one.

3. Results of optimum design.

The thermal and wind fields within the mountain-hollow space are formed mainly due to the energy supplied by solar radiation and the internal heat of the insolated urban stretch along the slopes and bottom of the basin. The interaction of insolation with an active surface of the building forms a thermal contrast, which is the result of the formation of the mobility mechanism of anabatic and katabatic kinds of winds and a means of intensifying natural air exchange by activating a turbulent mixing of air masses (fig.3).

The change in the thermal conditions of the building surfaces, caused by the insolation conditions, forms a thermal stratification of the hollow space along the vertical, and also the appearance of local flows intensifying natural air exchange in the mountain basin by activating a turbulent mixing of air masses.

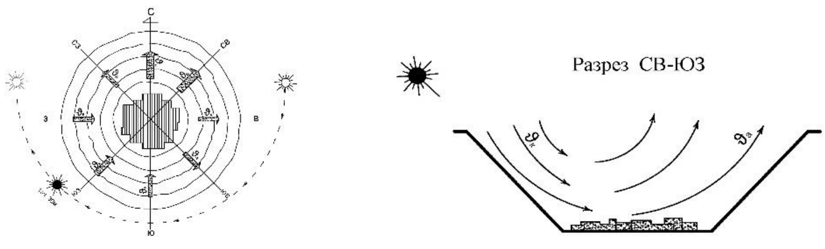

Fig. 3. Scheme of the formation of anabatical and katabatic winds

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In the daytime, due to intense insolation in the mountain basin, convective air movement occurs. At night - cool air draining along the slopes accumulates at the bottom of the valley, and displaces warmer air, which leads to the formation of an inverse structure of the surface air layer. The flowing air enters the deep part of the mountain basin, anthropogenic emissions are released on the terraces of the building. Dust is formed, as a result of which an array of cold, polluted air is formed in the building located on the bottom of the basin. Under its level, a speed of the streams does not exceed 0,2 m/s, a speed of the flowing katabatic air on the slopes 120 m in length with different steepness averages 1,5…2,2 m/s. After the sun rises and appears above the horizon, warming of the slopes begins, which leads to equalization of temperatures, destruction of the inversion and the appearance of a daily scheme of convective air circulation.

The distribution of solar energy during insolation within the hollow space in time shows those relationships that determine the thermodynamics of air flows.

Examination of the kinematics of air movement in the hilly terrain L. Prandtl [17] allowed the solution of the problem of convective motion on the slope of the mountains taking into account the friction of the rough surface of the building.

The velocity of the convective flow lifting anabatic on the slope taking into account an experimental coefficient, taking into account the roughness of the slope surface can be determined

$$v_a = K\sqrt{2g\,sin\alpha(H-Z)\left(\frac{\tau}{t_B}-1\right)}, \qquad (2)$$

where K - an experimental coefficient, which takes into account the deceleration of the convective flow for residential development with a dense, multi-storeyed development equal to 0.08 and a decompensated building equal to 0.2, and on average equal to 0.15; τ - average surface temperature of the slope, K; H - depth of a mountain hollow, m; Z - the depth of an arbitrary point, m.

Based on the analysis of calculated and experimental data, a relationship has been established that represents a change in the speed of the anabatic winds at different slopes and slope lengths. At the same time, the maximum speed of the anabatic wind of 5 m/s is observed at a high point of the slope length equal to 120 m with a steepness of 60 °. This local wind, flowing through the buildings erected on the slope, airs the buildings and adjacent building areas (fig. 4).

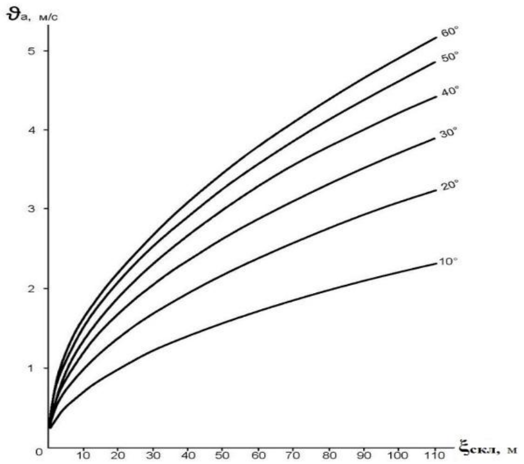

Fig. 4. Anabatic winds formed in the slope of the mountain basin

In the mountain basin with inversions, the cooled heavy air flows down all the slopes to its deepest part. Catabatic runoff is observed all night, accumulating at the bottom of the basin large masses of "lenses" of cool air.

In order to estimate the air flow rate under the influence of the gravity force of the catabatic flow along the slope, using the Lawrence formula [18], taking into account the slope length and the roughness of the slope development, the following calculation formula is presented below, which calculates the flow velocity of the catabatic wind along the slope

$$\upsilon_{к} = K\sqrt{2\,g\,\xi_{скл} sin\alpha\left(\frac{t_{в}-\tau}{\tau}\right)}, \qquad (3)$$

The aerodynamic coefficient of the windward and windward side of buildings of different exposures with respect to the direction of the characteristic local wind flow of anabatic and catabatic origin is determined by the agreement of the calculation formulas given in the table.

Table. Aerodynamic coefficients for buildings located on different parts of the slope of the basin

Parts of the building	Temper of the wind	Calculation formulas
Windward longitudinal wall	Anabatic upsurge	$K^{+} = 0{,}343 + 0{,}448\frac{X}{\xi}$
	Catabolic flow	$K^{+} = 0{,}208 + 0{,}22\frac{X}{\xi}$
Winded longitudinal wall	Anabatic upsurge	$K^{-} = -0{,}213 - 0{,}408\frac{X}{\xi}$
	Catabolic flow	$K^{-} = -0{,}105 - 0{,}18\frac{X}{\xi}$
End wall	Anabatic upsurge	$K^{-} = -0{,}513 + 0{,}285\frac{X}{\xi}$
	Catabolic flow	$K^{-} = -0{,}06 - 0{,}32\frac{X}{\xi}$

To determine other characteristics of the parameters of the convective flow that rises above the buildings on the slopes, one should use with appropriate adjustment and transformation of their structures in relation to the problem under consideration by the following calculation formulas [19].

Average velocity in the section of the rising stream

$$\upsilon_{a\,ср} = 0{,}42\frac{\nu}{\xi_{скл}}(Gr_{\xi}\;sin\alpha)^{\frac{1}{2}} \qquad (4)$$

Maximum speed in the section of the rising stream

$$\upsilon_{a\,max} = 2{,}42\frac{\nu}{\xi_{скл}}(Gr_{\xi}\;sin\alpha)^{1/2} \qquad (5)$$

The thickness of the boundary layer of the rising stream

$$\frac{\delta}{\xi_{скл}} = 4{,}5(Gr_{\xi}\;sin\alpha)^{-1/4} \qquad (6)$$

The air flow rate is calculated in the anabatic jet

$$Q = 2\,\nu\,\xi_{скл}\,(Gr_{\xi}\;sin\alpha)^{1/4} \qquad (7)$$

The following symbols are used in the formulas: Gr – a criterion Grashof, ν -kinematic viscosity of air.

Vertical upstream velocity of the thermal origin of the slope υ_a, when interacting with dynamic wind U is determined by the following dependency

$$\upsilon_a = U\,tg\alpha \qquad (8)$$

If we consider the building element of the slope surface of the mountain basin as a whole as a plate washed by a turbulent ascending flow, then to calculate the intensity of its heat transfer we should use the criterial equation [20].

$$Nu = 0{,}032\ Re^{0{,}8} \tag{9}$$

From expression (9) it follows that a heat transfer coefficient of the active surface of the built-up slope by the air flow depends on the velocity and temperature of the air-washing medium.

The amount of air W (m^3/ s) of a built-up mountain slope participating in the ventilation is determined taking into account the surface area S and the slope angle

$$W = \upsilon_a\ S\ cos\alpha \tag{10}$$

4. Conclusions

Based on the generalization and analysis of the results of studies of the structure of air currents, their direction, velocity and temperature fields, as well as microclimate characteristics in the development of the mountain-hollow space, a qualitative and quantitative aerodynamic picture of air movement resulting from the action of natural thermal forces is made.

The main physical quantities that determine the origin of this or that aeration scheme for the development of the mountain-hollow space is the degree of heating and cooling of the active surface of the building, erected in inclined and horizontal surfaces, which causes them to insolate.

Based on the analysis of the mathematical solution of the problem of convective motion on the slope and the generalization of the results of the field measurements carried out on the slopes, a computer program was compiled allowing quantitative and qualitative determination of the profile of developing anabatic and katabatic winds over the slopes of various steepness and exposure, which would solve the aeration problems for the stage of designing the planning, building and spatial solution of buildings.

As a result, it is noted that the compiled physico-mathematical model of aeration of buildings allows to predict the aerodynamics of architectural and building structures of settlements in the mountain-hollow space and determine their urban maneuverability. This model can be used in the practice of designing and building in determining the aerodynamic characteristics of buildings, wind loads and heat input through the infiltration of air through enclosing structures in buildings built on a complex terrain.

As a result of the research, the basic requirements for the volumetric-spatial form of buildings, architectural and planning and constructive solutions of buildings were formulated, and the typology of the dwelling erected in the mountain basin with rational use of anabatic and katabatic winds along slope development, taking into account the orographic features of the mountainous relief.

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