Model of Terraced House Construction on Complex Terrain

A Giyasov

1Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russian Federation

E-mail: adham52@mail.ru

Abstract. The analysis of the space-planning solution of terraced houses constructed on the slopes is carried out. It is a rational method of building residential houses whose advantages are the presence of large landscaped terraces and their isolation, which gives the apartments a resemblance to individual houses, compactness of building and formation of a comfortable environment in the rooms, integration with the terrain. At the same time, the multi-tiered location of houses along the slope gives the advantages to the development of multi-storey construction.

Methods of quantitative and qualitative assessment of climatic events based on geomorphological changes allowed developing a grapho-analytical method for assessing the microclimate of complex terrain, which is intended for residential construction. Due to microclimatic features, the search for ways of construction on the slopes made it possible to form the planning and spatial structure of terraced houses of different heights on complex terrain, depending on the high slope steepness degree.

1. Introduction

One of the most important socio-economic and urban problems of mountain countries is the development of mountain areas as residential areas, the use of these areas in the industrial, agricultural and socio-cultural development of the country.

The architecture of the mountain areas requires modern aesthetics and comfort, but the possibilities here are limited by the conditions of high complexity of the relief, seismicity, subsidence of the soil, and inaccessibility of the territory. Despite this, the limited nature and value of the land plots, the ruggedness of the terrain compel one to look for various spatial-compositional methods of rational use of the territory for settlements and separate buildings.

The development of complex terrain in today's rapid cities growth is particularly important. However, the absence of special types of buildings intended for mass construction on complex terrain leads to irrational territorial development of populated areas and cities with complicated functional zoning of relief territory and spatial, planning and constructive solution of buildings and their complexes.

Despite a lot of research on the formation of heat-wind processes, which are the determining factor of vital climatic, microclimatic, bioclimatic, and ecological environment of the mountain area caused by natural and climatic conditions-oroography, there is a number of problems in the field of urban development of complex terrain.

Special attention should be paid to the issues of accounting for complex mountainous relief at the planning stage of construction. In cities with a complex orographic situation, roughness of the
underlying surface, even in the presence of relatively low elevations and depressions, significantly change the environment of the built-up area, forming a zone of environmental disturbance and accumulation of negative atmospheric impurities, as well as the nature and direction of their dispersion should be taken into account.

Mountains affect the ecology of atmospheric space, as large fluctuations in elevation and complex terrain, causing an exceptional variety of natural and climatic conditions that determine the microclimatic and bioclimatic regimes of local character. All of these things complicate the problem of zoning the territory of complex mountainous relief on climatic characteristics and, subsequently, the principle of design of buildings and their complexes, planning structures of settlements as a whole.

Urban aspects of the complex terrain development, associated with the formation of settlements in the general system of settlement, were considered by a number of specialists [1, 2, 3, 4].

The influence of climatic factors on the formation of populated areas and the environmental aspects of urban planning in mountainous conditions were considered in the following scientific works [5, 6, 7, 8].

A number of studies by leading research institutes were devoted to the study of the landscape-climatic features and typology of the lowland dwelling and middle mountain regions [9, 10, 11]. They consider the circulation processes that form the climatic conditions within the mountain-valley systems of the southern regions of the CIS.

The issues of improving the architectural and planning structure of buildings on complex terrain were considered in the works [12, 13, 14, 15].

Complex terrain, with the aim of mastering the development of territories, is characterized by a set of dismemberment forms of the earth's surface and is divided by mega-, macro-, meso-, micro-, and nano-relief, which are used to solve specific urban planning tasks [16]. In this regard, orographic and climatic prerequisites for the planning structure of populated areas in complex terrain and features of designing and improving the architectural, planning and constructive structure of the dwelling and residential buildings in complex terrain have been developed lately.

The issues of shaping the topography of the potential construction, the formation of the planning organization of the relief characterized by a complex orographic situation, causing extreme low wind and calm conditions of zone aeration were considered in the works [17, 18, 19, 20].

Analysis of the urban planning practice in the conditions of countries that have mountainous areas and that are located in extremely warm windy climatic conditions shows that local climatic and environmental features are not sufficiently taken into account.

The aim of the study is to identify the mountainous areas that are distinguished by a complex orographic situation, causing extreme low-wind and calm conditions of the built-up areas, in this regard, to develop methods for planning and spatial organization of the residential buildings structure on complex terrain depending on the degree of steepness of the slopes.

2. Methods
To date, a large amount of studies has been carried out, and practical recommendations have been developed for improving the microclimate and eco-climate for reducing dust and gas pollution in lowland areas.

The existing methods of aerodynamic calculation, substantiation and choice of rational schemes and methods of natural ventilation of the mountain valley do not take into account the role of the insolation, thermal regimes in the natural air exchange of urban development [21].

Despite many studies in studying the issue of climatic conditions that determine the shaping of space-planning structures of buildings in complex terrain conditions, a certain problem which determined the directions of further theoretical studies and methods of large-scale in-situ measurements of climate parameters in characteristic areas of a mountain basin and valley was noted according to the methodology [21, 22, 24]. The study is based on the questions of the formation of thermal-wind processes in the mountain area caused by natural and climatic conditions - orography, as well as the thermal condition of the active built-up layer of the slope.
The following comprehensive research methodology based on the following provisions has been developed:

- morphometric assessment of the relief territory by constructing a map depicting the shape of the relief, which allow solving a number of applied problems, in particular, the assessment of temperature and wind conditions of the building;
- in-situ instrumental studies of microclimate and bioclimate factors in the mountain slopes, as well as in architectural and construction solutions of buildings on complex terrain in connection with the aeration regime;
- full-scale studies of meteorological factors of mountain slopes environment by methods of climatic, microclimatic and bioclimatic measurements;
- calculation of heat-wind processes of building in the slopes of the mountains with the use of computers;
- production of graph-analytical calculation of conditions of slope surface insolation in order to identify local winds.

3. Results

Quantitative and qualitative methods for assessing the orographic features of the relief’s shape of potential construction, depending on their scale, allowed making a plan for the description of the relief area for urban development, which includes the following main positions:

- General characteristics of the relief, relief shape (relief model) and its elements in the described territory;
- Orographic complexity of the relief;
- Natural and climatic conditions of the relief;
- The smallest and largest steepness of the slope;
- Exposure of the relief and the nature of the slope of the described territory, the conditions of insolation;
- Thermal regime of the active surface of the relief, conditions of aeration of the relief of the territory;
- Conclusion on the nature of the relief for urban development.

The instrumental methods of meteorological research revealed that in areas with a warm climate, wind and calm conditions are forming in mountain basins and canyons. At the same time, the mechanism of air movement, which contributes to aeration of the built-up slope area, the bottom of the basin and valley, is the interaction of insolation with the active surface of the slopes, forming thermal contrast and, as a result, sloping anabatic and katabatic winds of local origin, which favor aeration of the basin and valley space of the mountain relief.

The main reason for the formation of mountain-valley wind of complex terrain is the uneven distribution of important climate-forming factor - solar energy on the slopes of different exposure and steepness, in which anabatic and katabatic winds of a local nature are formed on the slopes of different exposure, depending on the conditions of insolation.

Anabatic winds, the uphill flow is associated with the daytime heating of the slope and the buoyancy force caused by this.

Katabatic winds are the winds of falling dense and cool air flow directed downwards along the slopes of the gravity flows caused by nocturnal radiative cooling near the surface.

The wind regime, which is described by the average wind speed of a local character on the site in the form of anabatic and katabatic winds of all directions, has the following form:
where \( \bar{v}_{ai} \) and \( \bar{v}_{ki} \) - average speed at the \( i \)-th site for anabatic and katabatic winds of all directions; 
\( v_{ai}^n, v_{ai}^{nw}, v_{ki}^n, v_{ki}^{nw} \) - the magnitudes of the velocity of the anabatic and katabatic winds on the \( i \)-th portion of the north, north-east corresponding direction; 
\( \Pi^n, \Pi^{nw} \) - the frequency of occurrence (%) of north and north-east wind direction.

Based on the analysis of computational and experimental data, a graph representing the dependence of the change in the speed of anabatic and katabatic winds on the slope steepness was constructed. With a steep slope of 60° and a length of 120m, the maximum speed of the anabatic wind gradually increases along the slope, reaching a maximum of 4.5 ... 5 m/s at a high point \( \zeta \) of the slope length. The maximum speed of the katabatic wind is 1.5 ... 2.2 m/s at the foot of the steepness of the slope, decreasing to 0.2 m/s at the top of the slope (Fig. 1). These winds, flowing around the buildings erected on the slope, contribute to the ventilation of the premises and the surrounding area, improving the ecological environment.

Studies to identify the aerodynamic characteristics of terraced buildings on models of 98x24x30 mm, located one block above each other, forming a terrace on a steepness of a slope, allowed us to determine the aerodynamic coefficient of the windward wall of 1, 2, 3 ... \( n \)-th stage, which depends on the geometric size of the stepped building whole (Fig. 2).
Figure 2. The dependence of the aerodynamic coefficient to the longitudinal axis of the terraced house on the geometric criterion Z in the flow of the slope wind.

The windward wall of the terraced building steps with a wind direction at an angle of 90° is experiencing excessive pressure characterized by average values of aerodynamic coefficients up to +0.45.

At $Z_{90}$ from 0.45 to 1.3, an increase in aerodynamic coefficients from 0 to +0.45 is observed, with a further increase in $Z_{90}$ from 1.31 to 1.6, the aerodynamic coefficient does not change.

Based on the processing of experimental data, the graphical and analytical dependence for the calculation of the aerodynamic coefficient is determined.

Based on the analysis of numerous modern space-spatial and planning methods of construction and buildings of different heights, erected in the form of a terrace on a complex terrain, systematizing recommendations have been developed in accordance with the tasks solved by the present work on the following signs.

According to the planning structure, terraced buildings are used on steep slopes of even 25-30 degrees. When located on the Sunny slopes (South-East, South-South-East), the maximum biological effect of the morning sunlight is ensured; when located on the Southern, South-West and Western slopes, overheating of the rooms can occur. Overheating of the rooms can be largely eliminated with the help of landscaping and gardening. With this technique, you can create an optimal microclimate in the rooms, effectively using the slope winds.

According to the high-rise solution, all types of buildings should be divided into methods of the same number of floors and methods of mixed number of floors with vertical blocking of buildings.

The main factors in the formation of the buildings microclimate are considered to be the long-term background regime of the terrain’s wind, as well as slope winds and their role in aerodynamics. At the same time, for the weather conditions of low wind, the initial data are given in the form of repeatability, speed and direction of the slope wind and the topographic sub-base of the relief area.

The search for ways of microclimatic features of the mountain slopes made it possible to form the planning and spatial structure of terraced buildings of different heights in complex terrain, depending on the degree of steepness of the slopes (Table).
Table 1. Space planning structure of terraced building.

| Scheme of space planning organization of a building | Principles of relief development | Advantages of a building |
|---------------------------------------------------|---------------------------------|--------------------------|
|                                                   | Maximum use of relief, minimum labor costs for earthworks |                         |
|                                                   | The use of favorable factors of mountain climate (insolation, wind slopes) |                         |
|                                                   | The presence of shaded aisles, courtyards, the possibility of arranging terraces |                         |
|                                                   | Compact building, fusion with the landscape |                         |
|                                                   | The possibility to construct buildings of the same type |                         |
|                                                   | Limited connection with the surrounding landscape |                         |
4. Discussion
When designing the residential buildings on complex terrain with a warm climate, the assessment of microclimatic factors of slope development in each case of the orientation of the relief is made separately by identifying a special regime of local slope rising and descending wind generated by the features of the underlying surface, orography and exposure. The data of meteorological stations in this case is taken as the initial.

With the development of urban construction in mountain areas and the formation of new urban neighborhoods and their structures, there is a need to take into account the impact of the degree of complexity of the relief, i.e. its shape, the exposure of ruggedness, and therefore the local microclimatic aeration modes of development. This affects the placement of buildings, layout planning, density and composition of buildings, the typology of buildings, etc.

5. Conclusions
Orographic features of the relief allowed depicting specific forms of relief and assessing the slope temperature-wind regime of the building, which is caused by the presence of a system of local winds, of which the slope and mountain-valley are most clearly manifested. It is established that the slope winds are formed by thermal circulation of low power between the slope and the plain.

The developed method for calculating the aerodynamic coefficient of the terraced building allows making an assessment and regulation of wind and temperature conditions, dispersion and distribution of harmful substances in architectural and planning solutions of buildings.

Orographic and climatic differences predetermined the prerequisites for the planning solution of development on the steep slopes of the terrain by drawing up the formation principles of the space-planning structure of the building. The search for ways of microclimatic features of the mountain slopes allowed forming the planning and spatial structure of the terraced residential buildings of different height on a complex terrain, depending on the degree of steepness of the slopes.

The existing architectural typology of terraced residential buildings and their planning organization for areas with complex relief, taking into account the peculiarities of the local climate of the landscape, was supplemented and clarified, and the design methodology formed within its framework was updated.

The presented space-spatial structures of terraced buildings with vertical blocking of residential cells are distinguished by town-planning maneuverability, are indispensable for the high steepness of the slope, irregularity and heterogeneity of the terrain, and also sufficiently effective in thermal engineering, significantly increasing their thermal efficiency.

6. Recommendation
In the planning of each specific space-spatial structure of buildings and construction, it is necessary to distinguish features specific to each planning scheme and type of buildings, taking into account local climatic conditions of the relief, which to the greatest extent determined the architectural and compositional and space-planning solution of the building depending on layout method relative to the slope.

References
[1] Town planning on the slopes 1988 Ed. Krogius Yu I (Moscow: Stroyzdat) p 328
[2] Levina E K 2011 Architecture in harmony with nature (Krasnoyarsk: Siberian Federal University) pp 13-18
[3] Trukhacheva G A, Khityova E O 2014 Principles of creating an architectural living environment with regard to the natural environment in a complex relief as a way to improve the quality of housing Technical Sciences - from theory to practice: Coll. Art. on mater. XXXIII international scientific - practical conference 4(29) (Novosibirsk: SibAK) pp 46-52
[4] Kurbatov Yu I 1988 Architectural forms and natural landscape: composite links (Leningrad: Publishing House of the Leningrad University) p 76
[5] Gornyak L 1982 The use of the territory with a complex relief for residential buildings (Moscow: Stroyzdat) p 72
[6] Recommendations on the integration of natural and climatic factors in the planning and improvement of cities and group systems of populated areas 1980 (Moscow) Central Research Institute for Urban Planning p 138
[7] Giyasov A, Gamzayev Sh R 2006 Residential development in difficult terrain and hot climate Housing construction (Moscow) 3 pp 227-28
[8] Giyasov A 2006 Aeration of buildings and structures Housing construction (Moscow) 3 pp 27-28
[9] Guidelines for the architectural and planning organization of residential development in coastal areas and complex terrain 1978 (Kiev) Kiev Scientific Research Institute of Urban Planning p 34
[10] Recommendations for the improvement of the urban environment 1980 (Tashkent) p 92
[11] Recommendations for improving the environment of residential buildings 1979 (Moscow) Central Research Institute for Urban Planning p 31
[12] Akbarov A 2014 Improvement of the architectural and planning structure of rural settlements in the conditions of the mountainous region of Tajikistan Abstract of dissertation for the doctor of architecture (Minsk) p 48
[13] Suvorov V O 2013 Typology of housing in a complex terrain on the architectural and spatial layout relative to the slope Fundamental and Applied Problems of Science: Materials VIII International Symposium 7 (Moscow) pp 11–16
[14] Kalabin A V 2012 House on relief (Ekaterinburg: Webster) p 160
[15] Shukurov I S, Giyasov A, Slepnev P A 2018 The residential area for mountain elevation settlements choice with the given structural features of the houses XXI International Scientific Conference on Advanced In Civil Engineering Construction the formation of living environment (Moscow) p 9
[16] Giyasov A 2018 Architectural-planning and constructive structures of residential buildings and buildings on complex terrain XXI International Scientific Conference on Advanced In Civil Engineering Construction the formation of living environment (Moscow) p 9
[17] Miller C A, Davenport A G 1998 Guidelines for the calculation of wind speed-ups in complex terrain J. Wind Engineering and Industrial Aerodynamics vol 74-76 pp 189-197
[18] Giyasov A, Sokolskaya O N 2016 Formation of urban development, taking into account the environmental factors of the atmospheric environment in hot low-wind and calm conditions (Krasnodar) «Print Terra» Limited Liability Company p 140
[19] Giyasov A, Krutikov Yu A, Gamzayev Sh R 2003 Building Aerodynamics Housing construction (Moscow) 6 pp 22-23
[20] Kharchenko S V 2013 The development of ideas about the relief as a factor in the wind microclimate of the city Geomorphology The New Generation Responsible Editor Kladovshchikova M E, Likhacheva E A (Moscow: Media PRESS) pp 38-45
[21] Giyasov A 2018 Modeling of Aeration of Buildings and Facilities Erected in a Mountain Valley International Multi-Conference on Industrial Engineering and Modern technologies IOP Conf. Series: Materials Science and Engineering p 6
[22] Guidelines for the production of microclimatic surveys during the survey period (Leningrad: Gidrometeoizdat) 1968 p 66
[23] Giyasov A, Tuskayeva Z R, Giyasova I V 2018 Using the features of a complex relief for the sustainable development of mountain areas Sustainable Development of Mountain Territories vol 10 4(38) pp 570-577
Acknowledgements
The work was carried out in accordance with the research plan of the Department of Design of Buildings and Structures of the National Research Moscow State University of Construction “Function, Construction and Environment in Building Architecture”.