MATEC Web of Conferences **396**, 08002 (2024) https://doi.org/10.1051/matecconf/202439608002
WMCAUS 2023

The impact of the orientation of family houses on a slope on the environment

Roman Ruhig[1*] and *Ema* Ruhigová[1]

[1]Department of architecture, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Radlinského 2766/11, 810 05 Old Town, Bratislava, Slovakia

Abstract. The contribution follows on from two previous researches, which dealt with the influence of the orientation of the construction of catalogue family houses from the point of view of CO_2 production during their operation. The previous research was focused on family houses (orientation of windows on all sides of the world) and terraced buildings (orientation of windows on two opposite sides of the world). The contribution in question is focused on family houses on a slope with one-sided orientation of the windows, which is the final phase of the research. The main reason for the overall research is the fact that developers are currently trying to realize the same type of family houses (catalogue houses) regardless of which side of the world the exposed glazed areas of the house are oriented. For this reason, the approval and energy certification often do not reach A0, which is a mandatory requirement of the energy assessment of buildings from 1 January 2021. The environmental impact research compares four basic types of streets with ten identical houses. The environmental impact research compares four types of basic streets with ten identical houses. if it is a comparison of the environmental impact of the same development of family houses on a slope, with different orientations to the cardinal points and with different local houses within the streets. The benefit of the research for practice will be the formulation of principles for the orientation of transparent areas in residential construction and the formulation of urban planning principles for the siting of houses in settlements on sloping terrain, where it is possible to place windows only on the front facade.

1 Introduction

Currently, on the outskirts of Bratislava (as well as on the outskirts of other Slovak cities), a large-scale construction of family houses is proposed and subsequently implemented, which has a significant impact on the environment not only through its construction, but also through the very operation of the buildings. From January 1, 2021, all new buildings in Slovakia must be built with almost zero energy consumption, classified in energy class A0 [1]. This is connected to the reduction of emissions during the operation of the given object, which results in an increase in the thickness of thermal insulation layers and the integration of technologies into buildings (such as recuperation units, heat pumps, photovoltaic panels, etc.). However, the energy efficiency of a building depends not only on quantitative calculations

* Corresponding author: roman.ruhig@stuba.sk

of the building's heat exchange envelope and the technology used, but also on the orientation of the building to the cardinal points and on the chosen substance, which affects the building's shape factor [2]. Few articles considered the effect of orientation, size and glazing properties [3,4,5]. However, the research on the influence of window size, position and orientation on energy load is still missing. As the building designs are getting more dynamic and complicated, more detailed and thorough analysis on various window design factors should be conducted [6]. Building costs are a result of a range of factors, and further research is required to investigate broader cost implications of volume-built designs with improved passive design performance. A frequent argument against increasing energy efficiency standards is that they lead to a requirement for more bespoke designs at increasing costs to builders, thus impacting upon affordability for consumers. On the contrary, this study indicates that house size is a critical factor in performance, and furthermore, that better performing designs require less adjustment across different orientations. This indicates that building standards regulation could be used to further drive energy efficiency standards without undermining affordability. It also indicates an opportunity for builders to provide more compact designs with passive solar features which are adaptable and therefore can be provided at a relatively lower cost than bespoke alternatives [7]. We often encounter the fact that developers implement the development of the territory with the same type of buildings, so-called catalog family house. It is built on land without changing the frontage and organization of the layout, regardless of which side of the world it is oriented to. Family houses on a slope are no exception. Based on the aforementioned, the basic research question was therefore established. If the family house meets the energy efficiency requirements and is classified in category A0 according to the global indicator, and we change the orientation of the house, will it have the same resulting values and be classified in the same category? The literature on passive solar design emphasizes the importance of orienting glazing for optimal solar gain, while balancing the glazing area, so that heat loss does not become too much of a factor on internal thermal performance [8]. A new generation of sustainable housing architecture is going to fuse the rules of sustainable development with aesthetic and technological principles. The orientation, form and size of objects, technological systems (including solar power solutions) as well as the specification of ecological effectiveness are now of equal status with other elements of the creative process [9]. For the reasons mentioned, the article in question is dedicated to researching the impact of the new requirements of the EHB (valid from 1.1.2021) on the possible regulation of family houses, specifically on family houses on a slope. The result should be a manual for urban planners who draw up spatial plans and for building authorities, for whom it is often enough to classify a family house in the energy category A0, but they do not check whether the world directions are well defined in the calculations according to the real placement of the house on the plot. Thanks to the given methodology, more consideration should be given to the influence of the orientation of family houses on a slope and the production of CO2 emissions during their operation.

2 Selection of the representative of the family house

The contribution follows on from two previous researches, which dealt with the influence of the orientation of the construction of catalog family houses from the point of view of CO2 production during their operation. Previous research focused on detached houses (orientation of windows on all sides of the world) and terraced buildings (orientation of windows on two opposite sides of the world). The contribution in question focuses on family houses on a slope with one-sided orientation of the windows, which is the final stage of the research. The research methodology remains the same in the article in question as it was in previous researches.

For the sake of an objective evaluation, it was necessary to find a representative who would represent the largest possible spectrum of family houses of this type. In Fig. 1 shows the design of a family house on a slope, which is based on an analogous procedure in order to include as many cases as possible of a similar type of family house on a slope in Slovakia.

In the first step, the size of the plot and its possible built-up area were selected. These data were taken from the binding part of the territorial plan of the capital of the Slovak Republic, Bratislava, where an average built-up area index of 0.22 is considered for detached houses from 600-1000 m^2 (function code: 102) [10]. Considering the current parcelization and the investor's need to sell the most optimal plot, a plot with a minimum area of 600 m^2 was chosen. The built-up area then represented an area of 132 m^2.

In the second step, the heated volume was determined at a design height of 3.35 m. The structural height consists of a clear height of 2.6 m [11] taken from the standard STN 734301 (which deals with residential buildings), the thickness of the floor fragment above the ground (the composition above the waterproofing: 100 mm thermal insulation + 80 mm underlying concrete with floor heating + 20 mm floor) and the thickness of the ceiling structure fragment (200 mm supporting structure + 350 mm thermal insulation). The thickness of the fragments and the choice of materials is defined by the minimum requirements for target recommended values according to STN 73 0540-2 Z2 [12]. In this step, the volume that will not be heated was separated. This represents the volume of a possible extension, garage, conservatory, or gazebo, which we do not have to consider within the heated volume. For this reason, only a built-up area of 120 m^2, above which only the heated volume is located, is further considered.

In the third step, the most exposed glazing facing the garden was designed. It was based on the hypothesis that the users of the house prefer the optical connection of the living room and bedrooms with the garden. For this reason, this facade was opened to the greatest extent possible. On the other facades, window structures are not considered due to the soil being sprinkled on each side. The position of the entrance door, which does not affect the energy rating of the building to such a large extent, is also neglected.

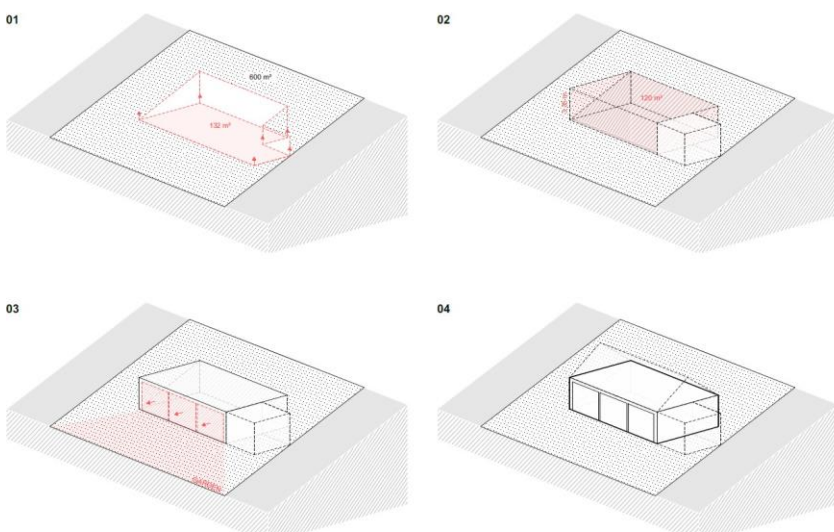

Fig. 1. Development of the mass of a representative house on a slope.

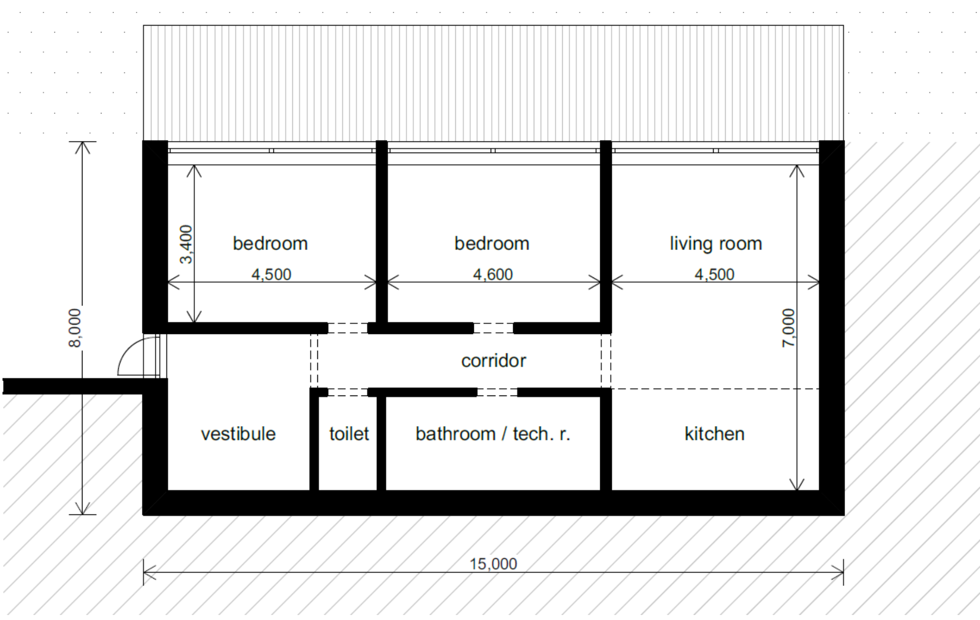

Fig. 2. Floor plan of a representative family house on a slope.

In the last, fourth step, the heated volume was defined, which was subsequently used in the calculation of the energy efficiency of the building. From the point of view of volume design, the object can be designed with a flat roof, a sloping roof, a counter roof, etc. As part of the research, however, a flat roof was considered, thanks to which the object has the most unfavourable shape factor of all variations (0.98 for a one-story object, 0.701 for a two-story object), which should have an impact on a more objective evaluation. The family house is considered as a detached house, so that it is considered with the most objective possible variant. The resulting layout has a rational layout with separate night and day zones and hygiene located in the center of the building. The rooms were designed with minimum dimensions, so that the object was profitable and the useful area of the house was used as much as possible for the living part (Fig. 2).

3 Input data for calculating the energy efficiency of the house

After selecting the representative and setting its parameters, enough inputs have been defined that require the calculation of the energy efficiency of the building. Subsequently, it was possible to compare the energy efficiency of the same family house with different orientations to the sides of the world. The boundary conditions were taken from the thermal engineering standard STN 73 0540-3 [13]. The case study was solved in the city of Bratislava, which according to the standard is located in temperature zone 1 with an altitude of 140 and wind zone 2. The external calculation temperature was considered for the city of Bratislava with a value of -11 ° C (calculation area - 10 ° C) with a design relative humidity of the outside air 83.2%. The suggested internal temperature used in apartment buildings (dwellings) was 20° C with a suggested relative humidity of 50%.

The last data that needed to be determined for the calculation of the need for primary energy and CO_2 emissions:

- the heat-exchange envelope of the building was designed with insulation, to the exact recommended values according to the standard STN 73 0540-2,
- an air exchange of 0.5 l/h was considered in the rooms (hygienic criterion),

- window shading was considered with a coefficient of 1.0 (in the summer months, shading would be ensured by exterior blinds. In the winter months, shading is not considered due to the use of maximum solar gains,
- in the family house, recuperation with an efficiency of 80% was proposed,
- the total permeability of solar energy g through the glazing was determined for all windows at a value of 0.5,
- the need for domestic hot water is considered equally in all variants,
- the same coefficient of thermal conductivity and thermal resistance as for the outer casing in contact with air is considered for the perimeter casing that was in contact with the ground
- the heating source was selected according to the most frequently installed heating system in Slovakia, which is natural gas [14].

The result of the calculations was the need for primary energy of the building and CO2 emissions in kg, which will be produced during the operation of the family house per year. Project evaluation calculations worked with standardized input data taken from STN 73 0540-2 [12] dealing with thermal protection of the building and its functional requirements. They should generalize the results and could be directly applied. The input parameters of the calculation are the same in all variants, except for orientations to the cardinal points and the size of the heated volume. In the calculations, two sizes of objects were calculated (one-story house, two-story house), where the objects have different shape factors. The calculation of the project assessment of the energy efficiency of the building was carried out with the help of the ISOVER Project Evaluation 1.0 (PEHA) program [15].

A family house in a terraced building was assessed with orientation to all sides of the world and was assessed as one-story (Fig. 3) and as two-story (Fig. 4), while the ratio of glazing to the non-transparent part of the facade remained the same. In this stage, 8 one-story and 8 two-story buildings were compared. As could be expected, the biggest difference in energy efficiency was between the buildings with the southern and northern orientation of the most exposed glass facade. The reason was the biggest difference in solar profits. For comparison: the specific primary energy requirement of a one-story building with south-facing exposed glazing was 44.622 [kWh/(m^2.a)] and with a north orientation 66.956 [kWh/(m^2.a)], which makes a difference of up to 33.36%. An important knowledge is that the same family house with south and south-east / south-west orientation of exposed glazing will reach energy category A0, but houses facing the other side of the world would be in energy category A1, which is a category where according to the currently valid legislation there is no such the house can be realized. The specific primary energy requirement of a two-story building with south orientation was calculated to be 23.582 [kWh/(m^2.a)] and 39.042 [kWh/(m^2.a)] for north orientation, which makes a difference of up to 39.60%. Variants oriented to all sides of the world reached the energy category A0 for the two-story building. The reason is the favourable shape factor. However, in the case of a two-story object, there is an important difference in calculations between objects with different orientations to the cardinal points, and it is more radical than in the case of a single-story object.

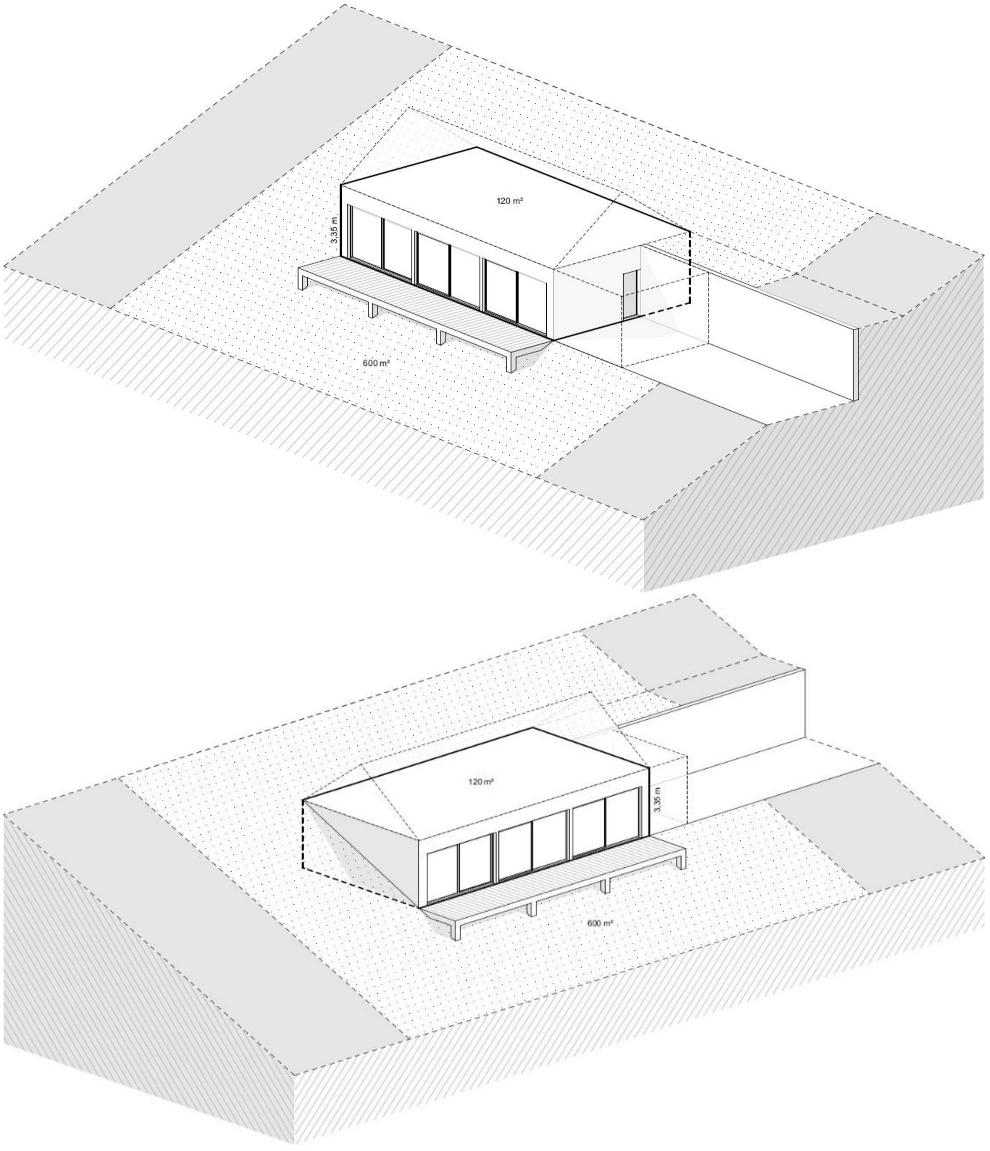

Fig. 3. Family house on a slope - one-storey building.

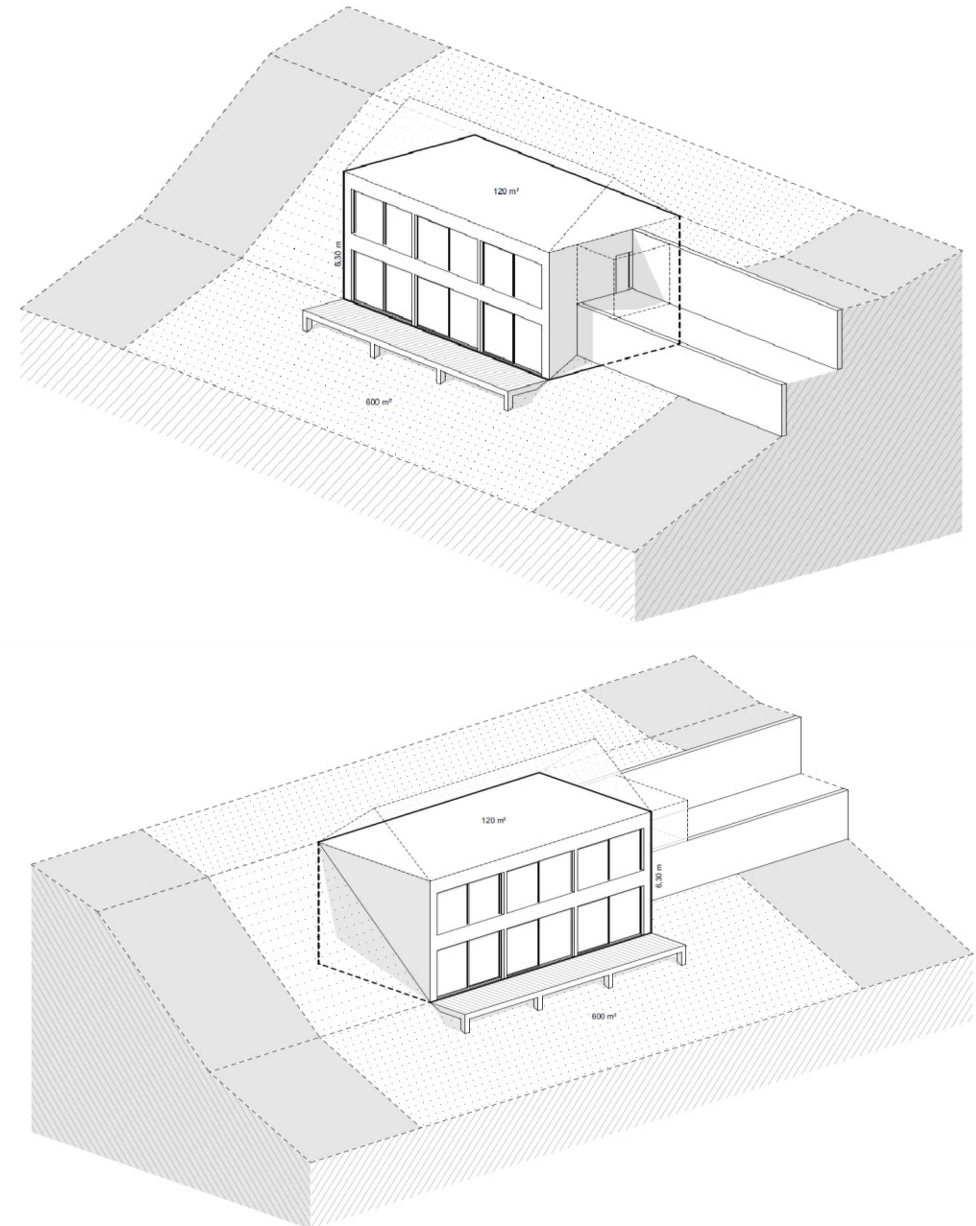

Fig. 4. Family house on a slope - two-storey building.

One of the other inputs could be a possible landslide under the proposed building and related measures. This aspect was neglected in the given research, but it is necessary to point out this fact and not forget it when implementing a similar type of construction in the hills.

The failure to identify the risk of landslide areas can significantly increase the cost of construction and building maintenance; threaten properties outside the scope of the planned intervention by construction; and, last but not least, endanger the lives of people on-site beyond the site construction [16].

For the example: The new municipality of Nižná Myšla was drafted in 2008 and allowed for the construction of new buildings on the territory of the landslide, which was activated in 2010. In case of later reactivation of the landslide in Nižná Myšľa, the landslide would have resulted most likely in damage of greater amount of objects. In addition to Nižná Myšľa in June 2010 large landslides were recorded also in Kapušany, Prešov, Vyšná Hutka, Vyšný Čaj, Varhaňovce and other locations where a total of 136 houses were damaged. All these sites were known from the Atlas of landslides and on most of the sites the construction of new buildings continued without appropriate measures. These facts, raise pressure on law makers to make it a law to have an obligation to respect known occurrences of landslides and landslides areas, when municipality plans are being prepared [17].

4 Influence of orientations of family homes on the environment

The paper in part continues the research and its results by F.H. Abanda and L. Byers. In the research in question, the researchers dealt with the influence of the orientation of the building on energy consumption. Based on the analysis of the energy consumption corresponding to the different orientations, it emerged that a well-oriented building can save a considerable amount of energy throughout its life cycle. The investigation has been successful in proving that building orientation impacts energy use and that the impact can be substantial [2]. From their research, it is clear that the orientation of the house has a significant impact on the energy efficiency of the building even with a smaller heated volume, and that the same building with different window sizes on facades facing different sides of the world can have different energy efficiency. The contribution also follows on from the research that was presented at the international conference Architecture in Perspective in Ostrava over the last two years. The conclusion of previous researches was that the difference in the production of emissions during the operation of a detached family house in some of the street developments is not so significant with different orientations [18]. Bigger differences arose in terraced buildings, where the windows are oriented only to two cardinal directions [19]. However, with the current demand for new buildings, these results are multiplied by the number of houses in new developments, which already leads to a significant negative impact on the environment. The research recommended the choice of other representatives, where the calculations would also be verified on a different type of building, with windows oriented only to one side of the world, as is the case, for example, in construction on slopes and in hills. This recommendation became the subject of this paper and a continuation of this research.

In previous researches, for the sake of objective comparison, four identical types of streets with ten houses, which are most often found in villages and towns in Slovakia, were selected. Streets with the development of family houses were assessed on all sides of the world. Given that the contribution in question focuses on development in the field, it was necessary to re-evaluate the possible types of streets (Fig. 5).

In variant A, the houses remain located on one side along the road, as was the case in previous researches. Opposite these houses there is not the same development (it is taken into account that the houses on the hill are not located on two banks and the road does not follow the crest of the hill). In variant B, the development is designed in an "L" shape and uses the orientation of the houses on two sides of the world. It is the most typical building on the hills. In variant C, the development is considered with orientation to 3 cardinal directions. It's a similar situation to building in nests, except that the objects are spaced apart based on the hill's morphology and therefore "X" is variable and can have different distances. However, this did not affect the set calculation, and for an objective evaluation, it is considered that the objects are next to each other. With all variants, the possible influence of the contours on the position of the houses is neglected, which could deviate the facade of the house more radically.

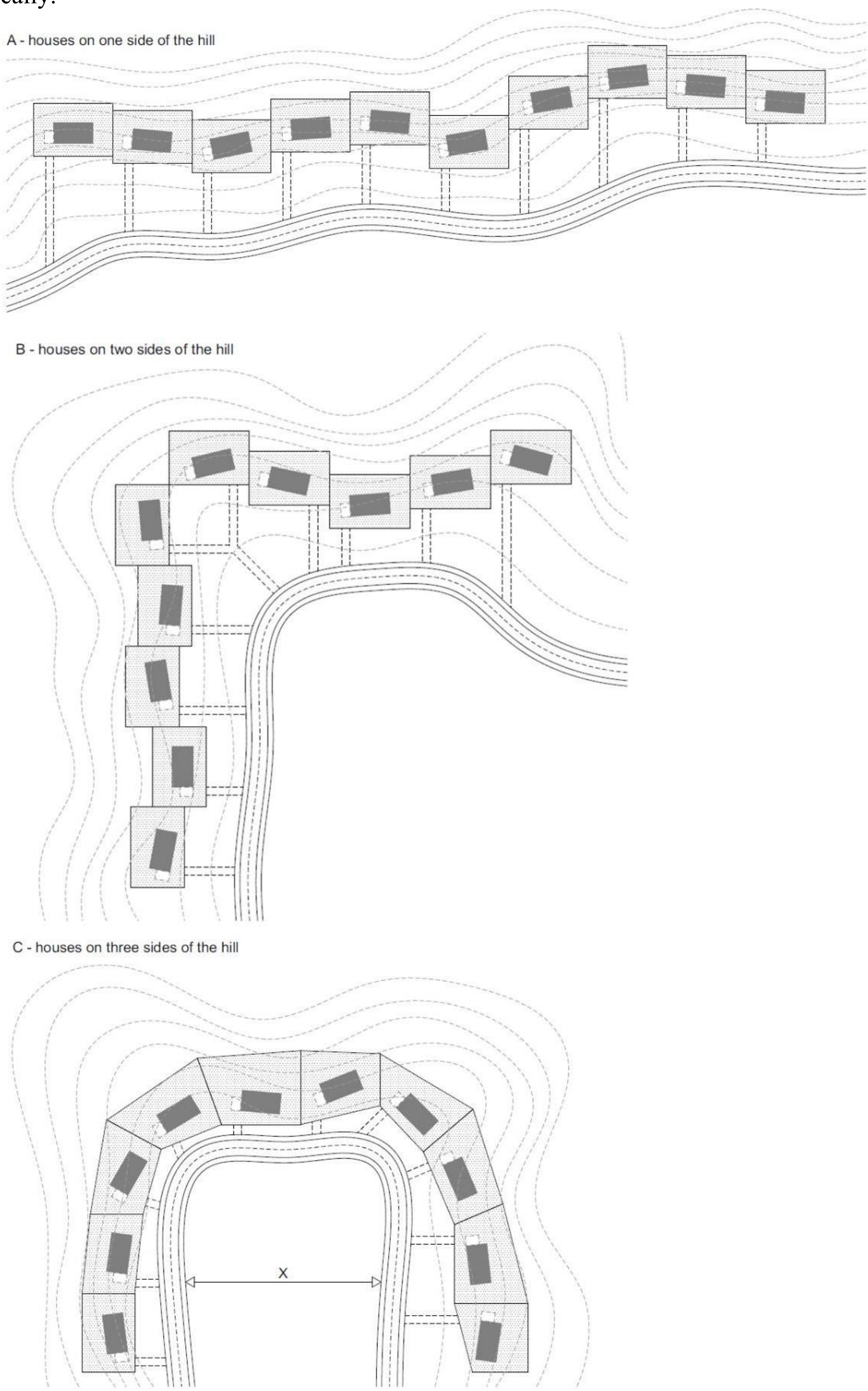

Fig. 5. Variants of the assessed streets.

A total of 24 variants were compared. However, some results for the given orientations are not shown, as the family houses have the same solar gains and the results of the energy efficiency of the building are also the same. The final evaluation reached 16 results, where eight were considered with one residential floor (table 1) and the remaining eight with two residential floors (table 2).

Table 1. Emission production results for single - storey buildings in variant situations – house on a slope.

ONE - storey house

A - houses on one side of the hill

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north	**16069,2**
south	**10708,8**
west / east	**13767,6**

B - houses on two sides of the hill

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north south	**14918,4**
east west	**12238,2**

C - houses on three sides of the hill

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north northeast northwest west east	**14891,28**
south southeast southwest west east	**12472,32**
west / east north south SE / SW NE / NW	**13606,08**

Table 2. Emission production results for two - storey buildings in variant situations – house on a slope

TWO - storey house

A - houses on one side of the hill

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north	**18739,2**
south	**11318,4**
west / east	**15636**

B - houses on both sides of the street

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north west / east	**17187,6**
south west / east	**13477,2**

C - houses on three sides of the hill

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north northeast northwest west east	**17164,8**
south southeast southwest west east	**13771,2**
west / east north south SE / SW NE / NW	**15346,56**

The tables show the results with total emissions produced by 10 family houses on a slope per year in a given street variant.

The smallest difference was for the street in variant C with one-story construction, where the difference between the construction to the north and east / west was 8.33%. The biggest difference in the results was when the two-story building was placed on a slope on only one side of the world – variant A. Specifically, between the location of the building on the north and south sides. The difference between these two orientations is up to 39.60%, which amounts to 7.42 tons of CO2 emissions per year. When designing a similar building with, for example, 100 houses, such a construction would make a difference of almost 74.20 tons of CO2 waste per year. One-sided construction on hills is a very common construction method. In variant B (L-street) the biggest difference in calculations was 17.97% (for single-storey buildings), 21.59% (for two-storey buildings) and for variant C (houses facing three cardinal directions within one part of the hill) 16.24% (for one-story buildings), 19.77% (for two-story buildings), which are not insignificant differences and can have a significant negative impact on the environment in the given development.

5 Conclusion

The research points to the impact of the orientation of the family building on the hill on the environment, where the one-sided orientation of the exposed glazing is a specific feature of the building. It is clear from the presented research that the orientation of exposed glazing in a given building has a significant impact on the overall energy efficiency of a family home, which is directly proportional to the CO2 emissions produced throughout the year.

In previous research that dealt with family construction on flat terrain, it was found that between one-sided construction with north and south construction (with 10 two-story houses) the biggest difference in emissions was as follows:

- for detached houses, the biggest difference was 1,368 kg per year, which was a difference of 9.79% [18],
- for terraced houses, the biggest difference was 3,470 kg per year, which was a difference of 21.67% [19].

In the subject research with one glazed facade, the differences between the northern and southern buildings were as follows:

- for a detached house on a slope, the biggest difference was 7,420 kg per year, which was a difference of 39.60%

Compared to individual family housing, this is almost a 5.5-fold difference and half the difference compared to terraced housing. For comparison: a gasoline-powered car that consumes 5 l/100 km and drives 15,000 km per year emits 1,792 tons into the air, assuming that the amount of carbon dioxide produced when burning 1 litre of fuel is 2,390 g [20]. This means that if a one-sided two-story building is built on the south side of the hill, with the same availability and solution of the facades, we can save as many tons of CO_2 compared to the building on the north side as four gasoline-powered cars produce in a year. An important knowledge brought by the research is also the fact that the same family house on the south and south-east / south-west side of the world will reach energy category A0, but houses oriented on the other side of the world would be in energy category A1, which is a category where, according to under current legislation, such a house cannot be built. This confirms the hypothesis that a family house on a slope with the same parameters cannot be unified as a catalogue house because it does not meet the energy criteria when placed on all sides of the world. As part of the research, family houses are analyzed, the windows of which are primarily located on only one facade. On the basis of the completed research, a methodology and recommendations for spatial planning should be issued, where orientations of the same types of family houses with an impact on the environment would be taken into account. This would prevent the construction of catalogue houses realized on all sides of the world, which may be in the energy category A0, but are only suitable when realized on some sides of the world.

References

1. Decree no. 364/2012 Coll. Decree of the Ministry of Transport, Construction and Regional Development of the Slovak Republic, which implements Act no. 555/2005 Coll. on the energy performance of buildings and on the amendment of certain laws as amended.
2. F.H. Abanda, L. Byers, An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling), Energy, 2016
3. K. Hassouneh, A. Alshboul, A. Al-Salaymeh, Influence of windows on the energy balance of apartment buildings in Amman, Energy Conversion and Management. 51, 2010, pp.1583–1591.
4. L. Vanhoutteghem, G.C.J. Skarning, C.A. Hviid, S. Svendsen, Impact of façade window design on energy, daylighting and thermal comfort in nearly zero-energy houses, Energy and Buildings 102, 2015, pp. 149–156.
5. S. Jaber, S. Ajib, Thermal and economic windows design for different climate zones, Energy and Buildings 43, 2011, pp. 3208–3215.
6. Soojung Kima, Puyan A. Zadehb, Sheryl Staub-Frenchc, Thomas Froesed, Belgin Terim Cavkae, Assessment of the Impact of Window Size, Position and Orientation on Building Energy Load Using BIM, International Conference on Sustainable Design, Engineering and Construction, 2016, pp.1424-1431
7. J. Morrissey, T. Moore, R.E. Horne. Affordable passive solar design in a temperate climate: An experiment in residential building orientation, Renewable energy, Melbourne, 2010
8. Spanos I, Simons M, Holmes KL. Cost savings by application of passive solar heating, Structural Survey, 2005, Vol. 23 No. 2. pp. 111-130
9. B. Majerska-Palubicka, Ecological aspects in current housing, Architecture in perspective, Ostrava, pp. 52 – 56, ISBN 978-80-248-4058-1, 2017
10. Spatial plan of the capital of the Slovak Republic, Bratislava, Part C.: Binding part of the territorial plan of the capital city of the Slovak Republic, Amendments 02, 2012, pp. 20
11. Slovak technical standard, STN 73 4301, Dweling buildings, 2021
12. Slovak technical standard, STN 73 0540-2+Z1+Z2, Thermal protection of buildings. Thermal performance of buildings and components, Part 2: Functional requirements, 2019
13. Slovak technical standard, STN 73 0540-3, Thermal protection of buildings. Thermal performance of buildings and components, Part 3: Properties of environments and building products, 2012
14. Information on https://vykurovanie24.sk/druhy-vykurovania/vykurovanie-plynom/ (accessed at 06/03/2023)

15. Computer program. ISOVER Project Evaluation 1.0 [online]. https://fragment.isover.sk/apps/v5_202302131012/html/projektove_hodnotenie.xhtml, (accessed at 06/03/2023)
16. J. Frankovská, M. Kopecký. Instability problems of cut slopes during the construction of expressways in Slovakia. In Geotechnical Engineering for Infrastructure and Development - Proceedings of the XVI European Conference on Soil Mechanics and Geotechnical Engineering, ECSMGE 2015 4, pp. 1543-1548, ISBN 978-0- 7277-6067-8, 2015, DOI:10.1680/ecsmge.60678
17. M. Kopecký, M. Ondrášik, D. Antolová, Atlas of Landslides in Slovakia. AGH Journal of mining and Geoengineering. AGH Krakow. Volume 36, No.1. pp. 211-217. ISSN 1732-6702. 2012
18. R. Ruhig, R. Ruhigová, The impact of the orientation of individual family houses on the environment, Architecture in perspective, Ostrava, 2021, pp. 80 – 84, ISBN 978-80-248-4552-4.
19. R. Ruhig, R. Ruhigová, The impact of the orientation of terraced family houses on the environment, Architecture in perspective, Ostrava, 2022, pp. 70 – 84, ISBN 978-80-248-4646-0.
20. Information on https://www.autolexicon.net/sk/articles/vypocet-emisi-co2/ (accessed at 06/03/2023)