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THE IMPACT OF THE ORIENTATION OF TERRACED FAMILY HOUSES ON THE ENVIRONMENT

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ABSTRACT: The paper follows up on the research that was presented at last year's Architecture in Perspective 2021 conference in Ostrava. Last year, the research dealt with the impact of the orientation of individual development of family houses on the environment in terms of CO2 production during their operation. The research methodology remains the same in the present article, but focuses primarily on the construction of terraced houses and houses that do not have windows on two sides. The reason is to check and compare the impact of orientations the toward on sides in denser construction. The main reason for the research is the fact that currently developers are trying to apply the same type of building (catalog houses) to all orientations the toward on sides, and with energy certification the problem arises of getting these family houses into energy category A0. This article deals with the research of the impact of the new requirements of energy assessment of buildings (valid from 1.1.2021) on the possible regulation of terraced buildings. Environmental research compares four basic types of streets with ten identical houses (single-storey and double-storey) in a terraced development, oriented to all sides of the world. The contribution of the research will be the formulation of principles for the orientation of transparent areas in residential construction and the formulation of urban principles for the location of terraced buildings in settlements.

KEYWORDS: oriented toward on sides; terraced house; energy efficiency; passive solar gains; CO2 emissions; environment; urbanism

INTRODUCTION

At present, in the outskirts of Bratislava (as well as in other Slovak cities), large-scale construction of family houses is being designed and subsequently implemented, which has a significant impact on the environment not only through its construction, but also through the operation of buildings. From 1 January 2021, all new buildings in Slovakia must be built with almost zero energy demand, classified in energy class A0 [1]. This is associated with reducing emissions during the operation of the buildings, which results in increasing the thickness of the thermal insulation layers and the integration of technologies into buildings (such as heat recovery units, heat pumps, etc.). However, the energy efficiency of a building may not only depend on the quantitative calculations of the building's heat exchange envelope and the technology used, but also on the orientation of the building to the world and the substance chosen, which also influences the building shape factor [18]. Few articles considered the effect of orientation, size and glazing properties [2,3,4]. 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 [5]. 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 relatively lower cost than bespoke alternatives [6]. Most developers offer for sale the same type of real estate called catalog house. It is without change of facade and organization disposition built on land with not the same orientation to the sides of the world. Family houses in terraced houses are no exception. If a family house meets the requirements of energy efficiency and is classified in category A0 according to the global indicator and we change the orientation of the house, will it have the same result values and will it be classified in the same category? The literature on passive solar design emphasises the importance of orienting glazing for optimal solar gain, while balancing glazing area, so that heat loss does not become too much of a factor on internal thermal performance [7]. 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 [8]. For the reasons mentioned, the article deals with the research of the impact of the new EHB requirements (valid from 1.1.2021) on the possible regulation of terraced houses. The result should be a manual for spatial planning, which should also take into account the impact of the orientation of terraced houses and the production of CO2 emissions during their operation.

SELECTION OF A REPRESENTATIVE TERRACED HOUSE

Due to the objective evaluation, it was necessary to find a representative (a family house in a terraced development) which would represent the largest possible range of family houses of this type. Fig. 1shows the design of a family house in a terraced house, which is based on an analogous procedure so as to include as many cases of a similar type of family house in a terraced house in Slovakia.

In the first step, the size of the plot and its possible built-up area were chosen. These data were taken from the binding part of the zoning plan of the capital of the Slovak Republic Bratislava [9]. Due to the current parcelling and the investor's need to sell the most rational land, a land with a minimum area of 450 m2 was chosen. The built-up area then represented an area of 135 m^2.

In the second step, the heated volume was determined at a construction height of 3.35 m. The con-

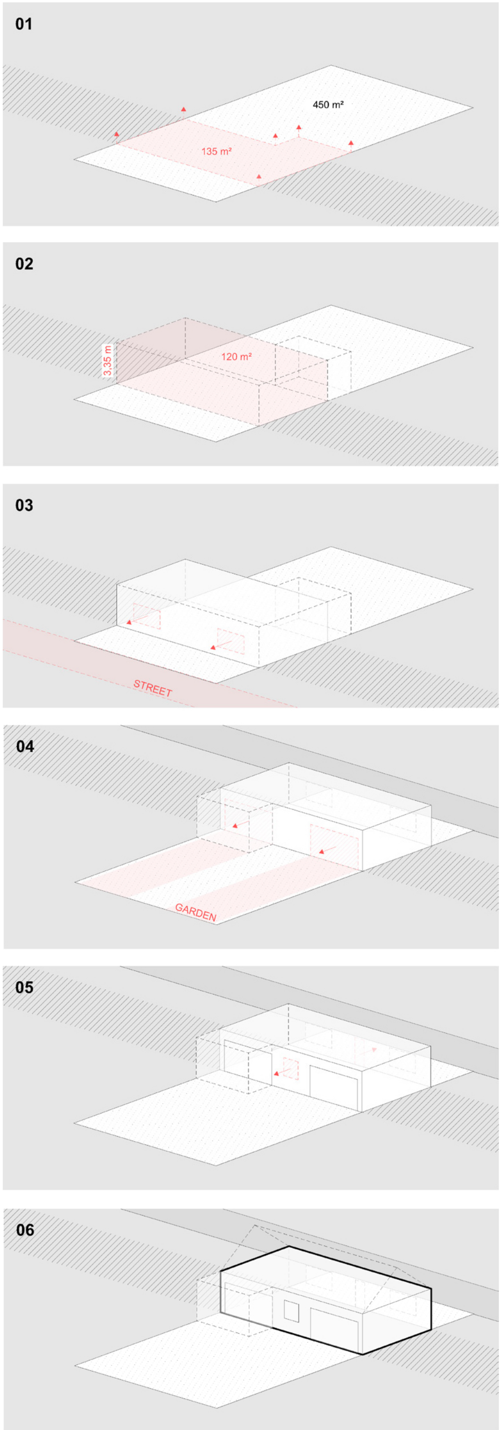

Fig. 1.: Development of the mass of a representative terraced house (Source: R. Ruhig, E. Ruhigová: submitted to conference Architecture in Perspective 2022)

struction height consists of a clear height of 2.6 m [10] taken from the standard STN 734301 (which deals with residential buildings), the thickness of the floor fragment above the ground (composition above the waterproofing: 100 mm thermal insulation + 80 mm base concrete with underfloor heating + 20 mm floor) and the thickness of the fragment of the ceiling structure (200 mm load-bearing structure + 350 thermal insulation). In this step, the volume that will not be heated was also separated. This represents the volume of a possible extension, conservatory or gazebo, which we do not have to consider within the heated volume. For this reason, it is further considered only with a built-up area of 120 m2, above which there is a heated volume.

In the third step, the windows to the street were installed, the size of which was designed according to the standard STN 73 0580-2 (dealing with daylighting of residential buildings) [11]. The window constructions were designed for the minimum dimensions of vertical windows in living rooms with one-sided side lighting. The size of the windows was affected by the clear height of the room (2.6 m), the width of the room (5.0 m) (Fig. 2) and the shading angle (0 °). The height of the windows was set at 1.5 m, from which the width of the window was derived according to the standard. The width of the windows facing the street was set at 2.75 m based on the above. The given size of the window was designed for one bedroom and kitchen.

In the fourth step, the most exposed glazing leading to 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 the master bedroom with the garden. For this reason, this facade was opened as much as possible.

In the fifth step, the windows to the other rooms, living room, bathroom / utility room were added. Their area depended on the selected maximum area of transparent structures on the house. The area of the glazing ranges from 30 to 50% of the perimeter wall area [12]. In one of the forums where this information was presented, the topic was developed by Ing. arch. Irena Dorotjaková. According to the architect, this size must depend even on its shading. Due to the need for profit from real estate, investors are usually inclined to use smaller window constructions. For this reason, glazing was also considered, which had only 30 percent of the facade of the building, which is the minimum on average. Due to the area of the perimeter wall (154.1 m^2 - area of the facade above the ground) and the already defined window sizes from the previous steps (34.25 m2), 30% remained = 4.50 m^2. It was this area that was distributed to the remaining windows - 2.25 m^2 in the bathrooms and 2.25 m^2 as entrance glass doors.

In the last sixth step, the heated volume was defined, which was then used in the calculation of the building's energy efficiency. In terms of volume design, the building can be solved with a flat roof, sloping roof, countertop roof, etc. However, the research considered a flat roof, thanks to which the object has the most unfavorable shape factor of all variations (0.98), which should have an impact on a more objective evaluation. Even if the family house is located in a terraced house, it is considered as a detached house, so that it is also considered with the most objective option possible, when the house can be at the end of a terraced house (it has no neighbor on one side) or the family house cannot have the windows on two sides due to the proximity of neighboring objects, which is common practice.

The resulting layout has a rational layout with a separate night and day zone and hygiene located in the center of the building. The rooms were designed with minimal dimensions so that the building is profitable and the usable area of the house was used as much as possible for the living area (Fig. 2).

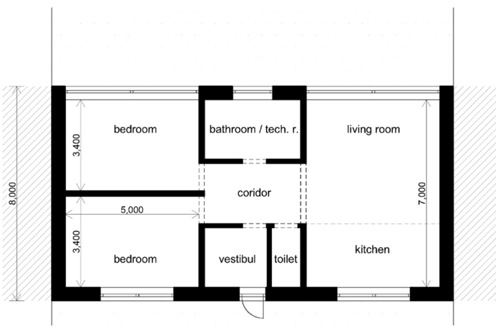

Fig. 2.: Floor plan of a representative terraced family house (Source: R. Ruhig, E. Ruhigová: submitted to conference Architecture in Perspective 2022)

INPUT DATA FOR CALCULATION OF THE HOUSE'S ENERGY ECONOMY

After selecting the representative and setting its parameters, a sufficient number of inputs was defined, which requires 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 world. Boundary conditions were taken from the thermal technical 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 area 1 with an altitude of 140 and wind area 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 proposed indoor temperature used in apartment buildings (dwellings) was 20 ° C with a design relative humidity of 50%.

The latest data that needed to be established to calculate primary energy demand and CO2 emissions:

• the heat-exchanging 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 (hygiene criterion),

• window shading was considered with a coefficient of 1.0 (shading would be provided by exterior blinds in the summer months. Shading is not considered in the winter months due to the use of maximum solar gains,

• recuperation with an efficiency of 80% has been proposed in the family house,

• the total solar transmittance "g" through the glazing was set at 0.5 for all windows

• the need for domestic hot water is considered in the same way in all variants,

• the heating source was selected according to the most frequently installed heating system in Slovakia, which is natural gas [14].

The results of the calculations were the building's primary energy demand and CO2 emissions in kg, which will be produced during the operation of the family house per year. The calculations of the project evaluation worked with standardized input data taken from the standard STN 73 0540-2 [15] dealing with the thermal protection of the building and its functional requirements. These should generalize the results and could be applied directly. The input parameters of the calculation are the same in all variants, except for the orientations to the sides of the world and the size of the heated volume. In the calculations, two sizes of objects were calculated (single-storey house, two-storey house), where the objects have a different shape factor. The calculation of the building's energy performance assessment was carried out using the ISOVER Project Evaluation 1.0 (PEHA) program [16].

The family house in a terraced development was assessed with an orientation to all corners of the world and was considered as one-storey (fig. 3) and as two-storey (fig. 4), while the ratio of glazing to the non-transparent part of the facade remained the same. In this stage, 8 single-storey and 8 double-storey buildings were compared. As expected, the biggest difference in energy efficiency was between the buildings with the southern and northern (more precisely northeast / northwest), where orientation of the building depends on the orientation of the most exposed glass facade. The reason was the biggest difference in solar gains. For comparison: the specific primary energy demand of a single-storey building with south-facing exposed glazing was 48.543 [kWh / (m^2.a)] and 59.222 [kWh / (m^2.a)] in the northern orientation, which makes a difference of 18%. An important finding is that the same family house in the south will narrowly fall into energy category A0, but houses oriented on the other sides of the world would be in energy category A1, which is a category which is not allowed under current legislation. The specific primary energy demand of a two-storey building in the southern orientation was calculated at 26.149 [kWh / (m^2.a)] and in the northern orientation 33.386 [kWh / (m^2.a)], which makes a difference 21.68%. Variants with an orientation to all corners of the world were included in the energy category A0 (is valid for a two-storey building). However, in the case of a two-storey building, the difference in calculations between buildings with different world orientations is important.

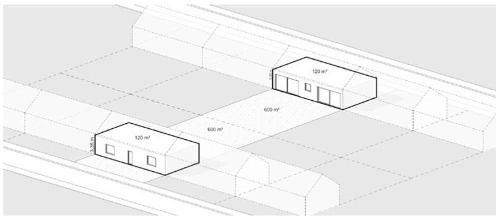

Fig. 3.: Terraced house - one-storey building (Source: R. Ruhig, E. Ruhigová: submitted to conference Architecture in Perspective 2022)

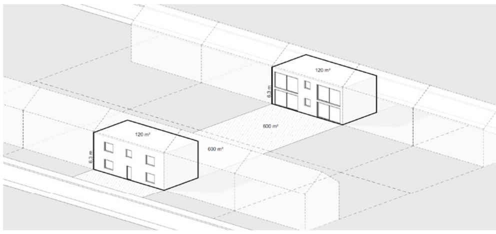

Fig. 4.: Terraced house - two-storey building (Source: R. Ruhig, E. Ruhigová: submitted to conference Architecture in Perspective 2022)

EFFECT OF HOUSES ORIENTATIONS ON THE ENVIRONMENT

The contribution continues in part in the research and its results F.H. Abanda and L.Byers. In this research, the researchers looked at the impact of the building's orientation 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 [17]. It is clear from their research that the orientation of the house has a significant impact on the energy efficiency of a building even with a smaller heated volume and that the same building with different window sizes on facades facing different sides of the world may have different energy efficiency. The paper also follows up on the research that was presented at last year's Architecture in Perspective 2021 conference in Ostrava. Last year, the research dealt with the impact of the orientation of individual development of family houses on the environment in terms of CO2 production during their operation. The conclusion of this research was that the difference in the production of emissions during the operation of a family house in some of the streets is not so significant in different orientations. However, with the current demand for new buildings, these results are multiplying by the number of houses in new buildings, which already leads to a significant negative impact on the environment [18]. The research recommended the choice of additional representatives, where the calculations would be verified on a different type of development, with the windows oriented to only two sides of the world, such as in series construction, or in houses with cramped conditions. This recommendation became the subject of the contribution and a continuation of the research.

As in the previous research, four identical types of streets with ten houses, which most often occur in municipalities and cities in Slovakia, were selected for objective comparison. Terraced streets have been assessed on all sides of the world. In variant A, the houses are located on one side along the road - in contrast to these houses, there is no similar development (the orientation of the houses in one direction is taken into account). In variant B, the construction is reflected around the central axis of the road. In this variant, the family houses are evenly distributed on both sides of the street. In variant C, the two streets are perpendicular to each other, which creates a T-junction and the family houses are always oriented in three directions. Houses oriented to a common nest are located in variant D. This variant is not so common, but here the houses are oriented in up to 5 directions.

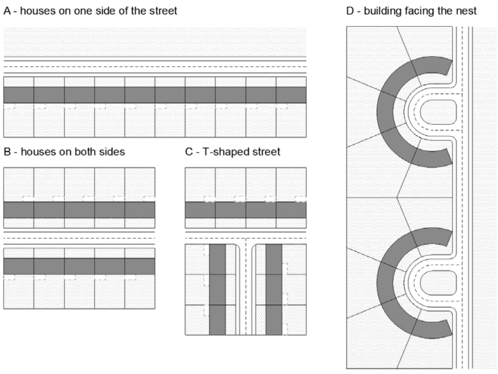

Fig. 5.: Variants of the assessed streets (Source: R. Ruhig, E. Ruhigová: submitted to conference Architecture in Perspective 2022)

A total of 32 variants were compared. However, some results for the given orientations are not given, as family houses have the same solar gains and the results of the building's energy efficiency are the same. 22 results were achieved in the final evaluation, where eleven houses were considered with one residential floor (Table 1) and the remaining eleven with two residential floors (Table 2).

The tables show the results with the total emissions produced by 10 family houses per year in a given street variant. The smallest difference was in the street in variant B with single-storey construction, where the difference between the north-south and east-west buildings was 5.41%. The biggest difference in the results was in the placement of terraced buildings on only one side of the world - variant A. Specifically, between the placement of buildings on the north and south sides. The difference between these two orientations is up to 21.67%, which is 3.47 tons of CO_2 emissions per year. When designing a similar development with, for example, 100 houses, such construction would make a difference of almost 35 tons of CO_2 waste per year. One-sided development of the same type of houses is not common. Most of the new buildings are mirrored around the central axis of the road. In some cases, however, terraced houses are located on only one side of the road, as is the case on the borders of urban and extra-urban areas, where there is agricultural land opposite the houses in the extra-urban area. However, there are also examples of streets where there is a function other than residential on the other side of the road (as opposed to family houses) (kindergartens, schools, civic amenities, public spaces, ...). In variant C (T-street), the largest difference in the calculations was 7.38% (for single-storey buildings), 8.8% (for two-storey buildings) and in variant D (nest-oriented houses), 8.27% (for single-storey buildings), 10.08% (for two-storey buildings), which are not negligible differences and may have some degree of negative impact on the environment.

ONE - storey house

A - houses on one side of the street

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north	14212,8
south	11650,8
west / east	13671,6

B - houses on both sides of the street

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north south	12931,8
east west	13671,6

C - T-shaped street

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north east west	13888,08
south east west	12863,28
west / east north south	13227,72

D - building facing the nest

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north northeast northwest west east	14050,56
south southeast southwest west east	12888,24
west / east north south SE / SW NE / NW	13321,44

Tab. 1.: Emission production results for single - storey buildings in variant situations - terraced house (Source: R. Ruhig, E. Ruhigová: submitted to conference Architecture in Perspective 2022)

TWO - storey house

A - houses on one side of the street

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north	16024,8
south	12552
west / east	15609,6

B - houses on both sides of the street

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north south	14288,4
east west	15609,6

C - T-shaped street

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north east west	15775,68
south east west	14386,56
west / east north south	14816,88

D - building facing the nest

Orientation (garden direction)	Emissions CO2 in kg/(a) - overall
north northeast northwest west east	16007,52
south southeast southwest west east	14393,28
west / east north south SE / SW NE / NW	14936,16

Tab. 2.: Emission production results for two - storey buildings in variant situations – terraced house (Source: R. Ruhig, E. Ruhigová: submitted to conference Architecture in Perspective 2022)

CONCLUSIONS

The research points to the impact of the orientation of terraced family construction on the environment and construction, which is in cramped conditions without window and door openings on the sides. From the presented research it is clear that the orientation of the exposed glazing in the given development has a significant impact on the overall energy efficiency of the family house, which is directly proportional to the CO_2 emissions produced during the year. In a previous study on individual family construction, it was found that there was a difference in emissions of 1,368 kg per year between unilateral buildings with northern and southern buildings (with 10 two-storey houses), a difference of 9.79% [18]. In the research in question, there was also the biggest difference between two-storey single-sided terraced buildings on the south and north sides. The difference in emissions was up to 3.473 tons, which is 21.67%. Compared to individual family houses, this is almost a twofold difference. By comparison, a petrol-powered car with a fuel consumption of 5 l / 100 km and which pass 15 000 km per year emits 1,792 tonnes, assuming that the amount of carbon dioxide produced by burning 1 liter of fuel is 2 390 g [19]. This means that if one-sided terraced development is carried out on the south side, with the same layout and façade design, we can save as many tons of CO2 as two petrol-powered cars produce per year. An important finding of the research is the fact that the same family house in the south will narrowly fall into energy category A0, but houses oriented on the other side of the world would be in energy category A1, which is a category in which realization is not allowed under current legislation. This confirms the hypothesis that a family house in a terraced house with the same parameters cannot be unified as a catalog house as it does not meet the energy criteria when realized on all sides of the world. In this way, family houses are analyzed in the overall research, the windows of which are located on all four perimeter walls (for individual family development) and only on two perimeter walls (for terraced development). The research should continue and verify another type of family house, which is a family house in the field, where the windows are located mainly on one facade. After investigation of this type of family house under a methodology and recommendations for spatial planning should be performed, which would take into account the orientations of the same types of family houses with an emphasis on their energy efficiency. This would prevent the construction of catalog houses implemented on all sides of the world, which are in the energy category A0, but only in the orientation to the southern side of the world.

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