COMPARATIVE STUDY OF HOUSES WITH DIFFERENT TYPOLOGIES IN TERMS OF ENERGY EFFICIENCY

Assoc. Prof. Dr. Tania Hapurne[1]
Prof. Dr. Irina Bliuc[2]
Lect. Dr. Aurora Irina Dumitrascu[3]
Lect. Dr. Calin Gabriel Corduban[4]
[1, 2, 3, 4] G.M. Cantacuzino Faculty of Architecture, Gheorghe Asachi Technical University, Romania

ABSTRACT

It is well established the importance of the initial design phase in the overall process of sustainable architecture. Strategies including: optimal orientation, the use of passive solar design, incorporation of low embodied energy materials, thermal efficiency of envelope systems, can be applied to a variety of residential buildings. From this standpoint, the main objective of this study is to demonstrate that the architectural object's scale is not that important, meaning that by using passive design strategies and innovative technical solutions can be obtained a similar energy performance over time for different home typologies.

Therefore, a house with a small indoor air volume versus a house with higher air volume can ensure comparable degrees of comfort and energy consumption per surface unit. To emphasize this statement a comparative analysis in terms of energy efficiency was made between two houses with almost identical enclosure elements and different sizes (a ground floor house – 90 square meters and a two story house – 210 square meters).

Keywords: *passive solar design, thermal efficiency, energy assessment, compactness, scale*

INTRODUCTION

The contemporary society is facing lately the sustainability challenge, requiring a holistic approach that brings together social, economic and environmental perspectives. The construction industry is an important consumer of energy and resources; therefore, all new design strategies must respond to the prerequisites of sustainable development.

The concern for energy efficiency plays a pivotal role and results in the optimization of design and constructive solutions for residential buildings [1]. The buildings account for over 40% of final energy consumption in the European Union, prompting the need for additional measures and policies in an effort to reduce the region's dependency on imports. In addition, in 2002, the residential sector was accountant for more 77% of green house emissions of all building stock, suggesting more rapid uptake of energy efficiency [2]. From the total energy consumed in the build environment, more than 60% is destined for heating and cooling the premises, with the rest consumed by lighting, electrical appliances and other uses, indicating the need to increase the thermal performance of building's skins as a first solution for reducing energy consumption and carbon emissions [3]. Other aspects that should not be ignored are related to building orientation, compactness, planimetric and spatial dimensions, shading devices, etc.

The present paper analyses the degree to which the architectural object’s scale influences the overall energy performance by comparison between 2 single family dwellings with similar geometry and thermal energetic data, but with different built volume.

The houses have been designed within the Modellus Research Grant Project (Model for a sustainable single-family dwelling), conducted at the “Gheorghe Asachi” Technical University of Iași, Faculty of Architecture. The project’s main objective aimed at designing 10 architectural solutions for single-family homes that meet the sustainability criteria (functionality, energy efficiency and minimal impact on the environment), based on the use of local materials (wood, natural stone, earth, wool, straw etc.) characterized by low embedded energy, that require medium-skilled workmanship [4].

ENVIRONMENTAL AND ENERGETICAL CRITERIA ADOPTED IN THE DESIGN STAGE

The sustainable design translates into a complex set of principles to encompass areas related to environment, economy and society and the collaboration of disciplines to include these domains. From an architectural standpoint, in the conceptual stage, these measures can be grouped in two major categories: conformation and building physics, that intersect and are all subordinate to the principles of passive solar design. The approach should be, from the beginning, one that takes into account a life-cycle scenario.

Conformation

- *orientation* of the building often functions as a starting design point and is therefore a very important characteristic to architects. The main concern regards the ways to use natural light for solar gains in winter season in parallel to achieving simple and effective forms of shading in summer, as well as the impact they create on architectural expression and interior design;

- *flexibility* fundamentally embodies a life-cycle approach to design. Incorporation of modularity and adaptive re-use represents a premise for durability in the context in which a residential building may go through various forms of existence. The adaptability of a building to changes translates in time to less costly, quicker changeovers in space-use [5];

Energy efficiency strategies

- improving *envelope energy performance* by utilizing recent advances in materials and know-how is a cost-effective long-term strategy. Reducing cooling and heating requirements due to heat gain/loss through the building envelope elements has a major impact on the life cycle costs. Although the insulation requirements specified by national regulations have constantly raised the comfort standards, this issue is better understood at the level of final users in terms of the economy over time.

- *materials* utilized have to respond to two main criteria: environmental (low-embodied energy, local availability, ability to be recycled) and health (non-toxicity and limitation of fire-hazard);

- *using the thermal mass* employing materials and construction elements with certain consistency / thickness, precisely to ensure the storage of heat, in daytime and released at night or when indoor temperature falls below the thermal mass.

- *optimizing ventilation* in order to ensure the quality of indoor environment and to reduce the energy demand for cooling.

PROPOSALS FOR ENERGY EFFICIENT HOUSES

The architectural models were elaborated following a complex study, which focused on both the optimization in architectural terms, obtaining solutions with high functional and aesthetic qualities; and on the other hand, the integration of innovative constructive solutions, by capitalizing on local resources (wood, clay, stone), for high energy performance, figure 1.

M01 – ground floor house *M02* – two storey house

Figure 1. Architectural sollutions for the evaluated houses (Renderings, specific sections and first-floor plans)

The first house, M01 is a ground floor dwelling with a gross area of approximately 90 square meters, which can be placed on a slope or flat terrain, by vertically adjusting the night zone in relation to the day zone. Architectural style is contemporary minimalist, with generous glazed surfaces, through which an optimal communication is achieved between the interior and the exterior. The house reinterprets elements of traditional architecture such as the intermediate protected space or the rhythm and proportion of the wooden columns in the living area. The dwelling is a small one with a living area and a bedroom, but it allows extension on two sides with additional spaces. On the southern and eastern sides are generous, sheltered terraces that allow for outdoor activities, whose proportions, functional and shadowing role are inspired by the traditional dwelling. From a constructive point of view, the structure is modular, entirely made of wood, including the ground floor slab, positioned on poles. This system allows for easy end-of-life dismantling and relocation with minimal impact on the environment. In order to ensure the thermal mass, a medium clay wall is proposed, separating the day zone from the night area. Through compact form, minimalist architecture and flexible functionality, the proposed solution is versatile, compatible in various contexts: location, family structure, and destination.

The second house, M02 is a two story detached dwelling with a gross area of approximately 210 square meters, whose concept is the north-south duality. The project aims for a generous glazing to the south and the layout of the main spaces with this orientation, in contrast to a compact façade to the north and the orientation of the secondary spaces in that direction. Although the projected image is one of modern expressiveness, the inspiration for the concept comes from traditional Romanian houses, which invariably have a porch and south-facing rooms and a roof that descends almost to the ground to the north, regardless of context. The interior space is fluid and flexible, with the double-height living room ensuring visual communication between various spaces. At the same time, the functional solution allows, without changing the facades or structural elements, various re-partitions, both at the ground and the floor level, thus meeting the time evolution needs of a family with 1or 2 children. The lamellar wooden structure designed for the slabs of this dwelling remains partially apparent, for greater expressiveness and is found with the same geometric pattern at the exterior finishes following a unitary concept. The same structure is also placed on the outside of the south windows, as a support for plants with falling leaves to ensure summer shading and maximize solar intake during winter. The staircase enclosed in the greenhouse is supported on a thick clay wall designed to improve thermal inertia. The contemporary style of the dwelling makes the elements inspired by the Romanian archetypal architecture more difficult to reveal, although they are found in all the components of the house, from: the geometry of the structure, the stratification of the exterior walls including adobe masonry, the finishes (white plaster and wood), to subtle interpretations of the intermediate space of the porch and the relation between household functions.

ENVIRONMENTAL EVALUATION, RESULTS AND DISCUSSIONS

The energy performances of the models have been evaluated by numerical simulations using specialized programs (ArchiCAD Eco Design software). Specific key indicators have been determined, including:

- *specific annual energy consumption for heating (q_i),* expressed in kWh/m^{2}a, means the energy required to maintain comfort indoor air conditions in the cold season and is based on the building's heat losses [3];
- *specific annual energy consumption for cooling (q_r),* expressed in kWh/m^{2}a, is calculated from the net cooling energy need during the worm months, taking into account losses from generating, storing, distributing, and transfer as well as conversions [3];
- *annual impact on the environment* estimated by the equivalent emission index, expressed in kgCO_2/m^{2}a,

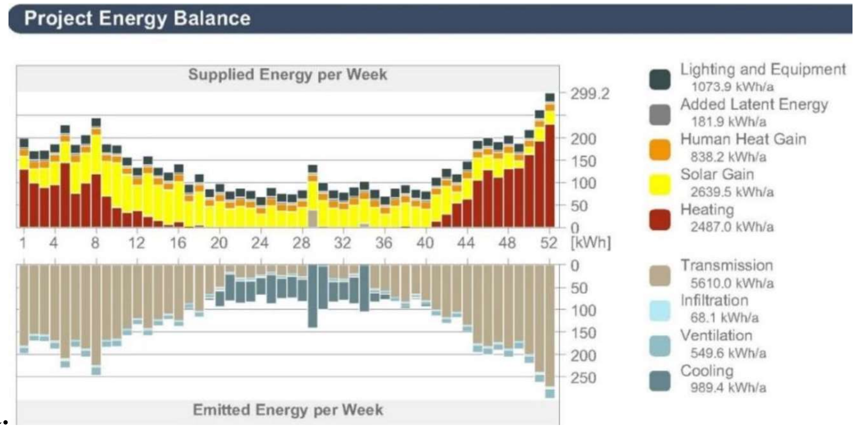
In addition, the program provides detailed information on heat loss, energy consumption for lighting, solar gains and internal gains.

A detailed model of each house was designed using the software, conducting to an accurate evaluation that takes into account the precise geometry of the solutions. The inputs are based on the computed values of the adjusted thermal resistances for each specific element, in accordance to Romanian standards. Both solutions use the same stratifications for envelope elements and, consequently, the average thermal resistances per each house have close values, 3.33 m^{2}K/W for *M01* and 3.45 m^{2}K/W for *M02* (the 5% difference is in favor of *M02* model). The characteristic geometric parameters for the 2 houses, taken into account in the energy evaluation, are shown below in Table 1.

Table1. Building geometry data for the two houses

Model	Total Area A [m^2]	Heated/Ventilated Volume V [m^3]	Building Skin Surface A_a [m^2]	Compactness A/V [m^{-1}]	Glazing Ratio [%]
M01	90.89	201.06	172.04	0.855	21
M02	208.94	474.91	416.68	0.872	20

The results of the comparative study, figure 2, indicate a high level of energy efficiency, characterized by the low annual energy consumption for both dwellings.



a.

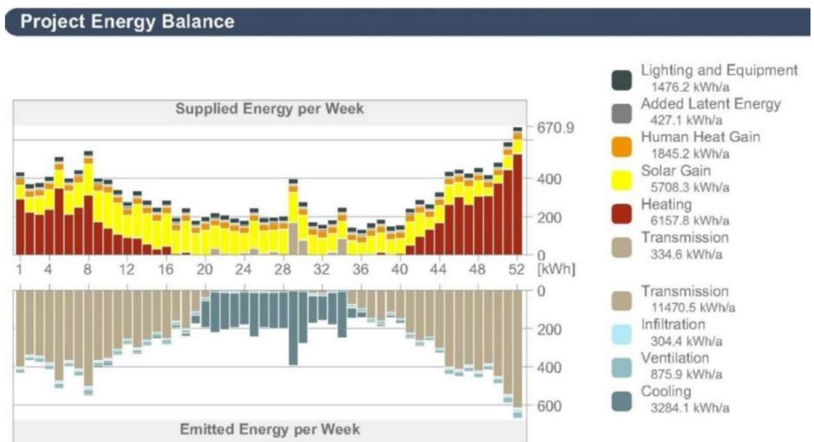


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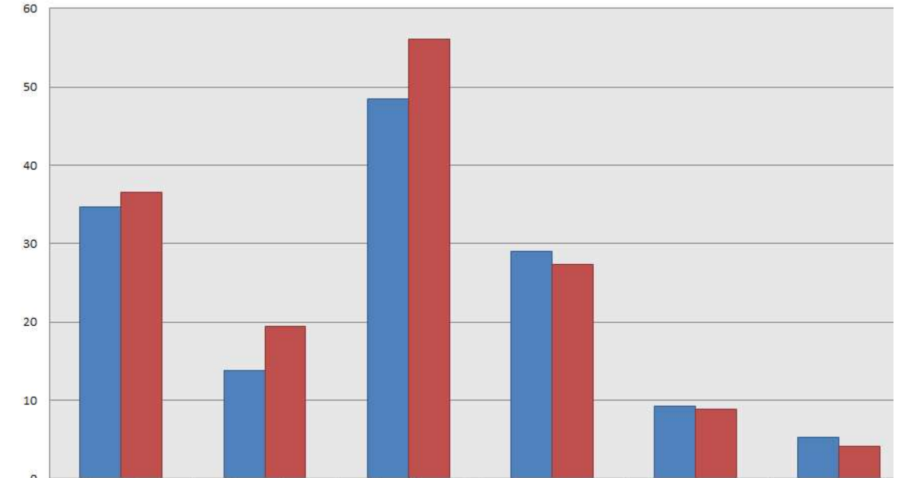
Figure 2. Results - Eco Design simulations for the proposed models: Energy balance

a. *M01* house model; **b.** *M02* house model

The values obtained through design simulations are presented as a comparative analysis in Figure 3.



	Specific annual energy consumption for Heating qi [kWh/m²a]	Specific annual energy consumption for Cooling qr [kWh/m²a]	Total specific annual energy consumption q [kWh/m²a]	Specific solar gains qr [kWh/m²a]	Internal gains qint [kWh/m²a]	CO2 Index [kg/m²a]
M01	34,66	13,79	48,44	29,04	9,22	5,23
M02	36,54	19,49	56,03	27,32	8,83	4,16

Figure 3. Comparative simulation results

Analyzing the simulation results for the two models, we can conclude that although the values of average thermal resistances are very close, the total specific energy consumption differs by approx. 15% in favor of the *M01* model. This aspect can be explained by the difference that occurs between the cooling consumption values, the *M01* model having a 30% lower value than the *M02*, although both models benefit from an approximately equal area of shaded terrace. This can be attributed to M02's two stories that modify the building's spatial configuration, thus reducing the protective effect of the shaded terrace against solar radiation. At the same time, the solar input is reduced by about 6%, although the percentage of glazing in the two models is similar.

The specific energy demands for heating have close values (5% difference), therefore both models can be included in the LOW category, figure 4.

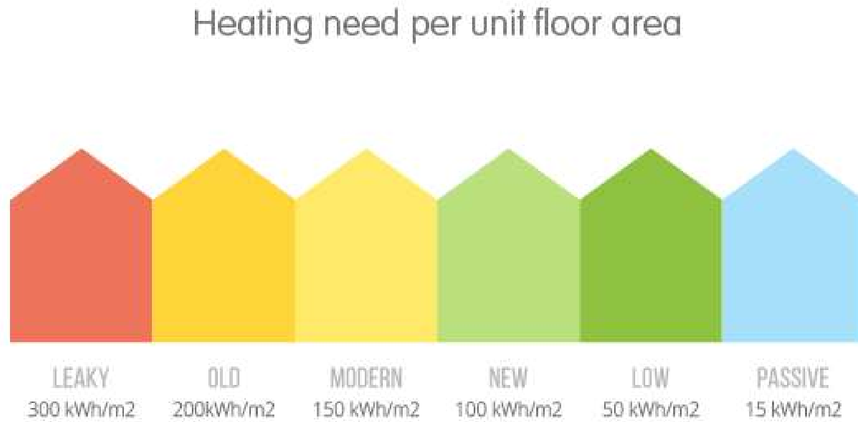


Figure 4. Towards passive house, heating need per unit floor area clasification [6]

The CO_2 emissions related to the two models are similar in value. This result confirms a broader study that indicates that for houses with higher levels of thermal performance, the size itself is a less significant factor of overall emissions [7].

CONCLUSION

The comparative study emphasises the importance of both passive solar design measures and thermal efficient solutions for envelope elements in the case of detached houses. Provided these measures are implemented, the overall scale of the house plays a lesser role in terms of energy performance.

The total specific energy consumption for operation for the two analyzed models is significantly influenced by the cooling energy demand (also influenced by the spatial configuration of the building). Energy consumption can be further diminished by additional measures to protect the glazed surfaces from solar radiation such as blinds, shutters or windows with selective optics. The comparative study emphasizes the need for an energy analysis from the earliest stages of design, in order to choose the most efficient solutions and measures to reduce energy consumption and greenhouse gas emissions.

Although this study indicates that size itself is not as important regarding energy consumption per surface unit, it is obvious that the increment in energy use is in direct proportion to the overall scale of a building.

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