Analyzing the Window-to-Wall Ratio in School Facades of Osijek-Baranja County in Croatia

Hana Begić[1*)] and Hrvoje Krstić[2)]

[1)] Faculty of Civil Engineering and Architecture Osijek, Josip Juraj Strossmayer University of Osijek, Croatia; email: hbegic@gfos.hr; https://orcid.org/0000-0001-9082-2881

[2)] Faculty of Civil Engineering and Architecture Osijek, Josip Juraj Strossmayer University of Osijek, Croatia; email: hrvoje.krstic@gfos.hr; https://orcid.org/0000-0001-5118-4186

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Abstract

This study investigates the relationship between Window-to-Wall Ratio (WWR) and energy consumption in educational buildings, focusing on elementary and high schools in Osijek-Baranja County in Croatia. Given the substantial energy consumption associated with buildings and the imperative to mitigate environmental impact, early design decisions are crucial in shaping building performance. However, limited research exists on the energy performance of educational buildings despite their significance in providing conducive learning environments and promoting environmental consciousness among students. The analysis reveals a significant variability in WWR values and a strong link between WWR and cooling energy consumption, highlighting the impact of architectural design on energy demands in educational buildings. The findings underscore the importance of optimizing WWR to minimize energy consumption and enhance indoor comfort in educational settings.

Keywords: *school buildings, energy consumption, window-to-wall ratio, energy efficiency*

1. Introduction

Early design choices have a big impact on how well a building performs in the future [1-4]. Since buildings have been found to account for more than 40% of energy consumption in some developing countries, this problem is the subject of numerous research and highlight the importance of early design [5-7]. Also, according to the Energy in Croatia 2021 report, in Croatia, the total energy consumption in buildings accounts for over 47% of the final energy consumption (Figure 1).

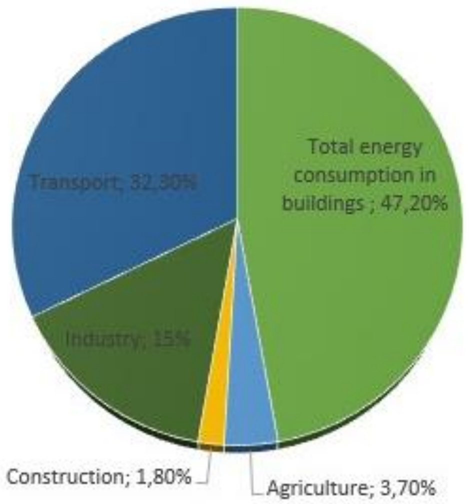

Fig. 1. Share of total consumption in buildings in 2021 in final energy consumption.

Therefore, to design a net zero-energy building, it is imperative that building performance modeling tools are actively used in the design stage [8, 9]. A low-energy building can be made to consume less energy by installing enough thermal insulation, thermally efficient windows, and thoughtfully planned shading to minimize heat transfer through the envelope [10]. Therefore, to achieve optimal energy consumption and an excellent indoor environment, choosing the appropriate glazing type of windows and their proportion to the total wall area, i.e. window to wall ratio (WWR) is necessary. This is since glazing quality, size, frames, and dividers contribute to heat gain and daylighting [11, 12]. Also, the demanding energy standards have led to a global tendency toward a larger share of glass wall surfaces [10]. The ideal WWR value is defined in the literature as the one that minimizes the total annual energy consumption for lighting, cooling, and heating [13]. Because of the building's intended appearance, the WWR is frequently selected during the design phase without taking its future energy performance into account. Since energy modelers and experts are not involved in the early stages of design, WWR is heavily dependent on the design concepts of architects and the expectations of clients [14]. Therefore, it is important to make this selection at the start of the project since it, in most cases, is not subject to later changes as it is with materials, equipment and operations [13]. As previously said, giving users a thermally comfortable environment is one of a building's major advantages.

Concerns regarding energy-building performance have grown recently among designers, engineers, and other industry experts. On the other hand, a lot of work has been done on residential and commercial buildings in the literature, but not much on buildings for education [15]. However, it is undeniable that a suitable learning environment benefits the health and wellbeing of instructors and pupils, which makes these kinds of buildings crucial in this regard [16]. Additionally, schools are different from other kinds of buildings since they serve as places of education and instruction for young people, giving them the chance to learn how to be environmentally conscious citizens [17]. Additionally, the cost of operating schools is significantly impacted by the amount of energy used; energy expenses rank second in importance only to teacher and staff wages [18].

2. Literature Review

The authors, Didwania et al., emphasized the importance of optimizing WWR. They suggested use the GenOpt software for optimization, and they used a case study office building to analyze the best WWR for the top and ground floor with independent window distribution on all four sides. The results showed that the ground floor allows for a higher optimum WWR and that the independent distribution of glazing on all four directions should be preferred rather than symmetric one since the symmetric one results in a much lower WWR [11].

Author Goia investigated the optimal WWR in many European regions for an office building. The results demonstrate that, although there exists an optimal WWR for each direction and environment, most of these values are in the range of 30 to 45%. Additionally, the author notes that the overall energy usage may increase by up to 25% when the most undesirable WWR configuration is utilized instead of the ideal WWR [13].

In order to establish acceptable default values of WWR in Japan for design performance modeling, authors Wen et al. presented a methodology for constructing WWR maps. The integrated models take into account the following design conditions related to building geometry and principal application: illumination power density, climate, window orientation, internal gains, and building scale. Based on the results, they recommend that a moderate default value of WWR of 30–50% be suggested and that design performance modeling be incorporated into the design process [14].

Authors Alghoul et al. researched into how WWR affected heating, cooling, and overall energy use. In a case study they presented, the external walls of a small work space in Tripoli, Libya, were analyzed, and the WWR varied from 0 to 90%. The findings show that raising WWR causes cooling energy consumption to rise while heating energy consumption falls. The authors recommend obtaining a more extended version of the correlation between window orientation, WWR, and total energy use as a direction for further research and also highlight that more research is needed to develop this correlation for various wall and window types and locations worldwide [19].

The impacts of thermal insulation, shading devices, WWR, and a combination of these features were examined by authors Alwetaishi and Taki in a prototype school building design in the warm climate city of Taif, Saudi Arabia. According to the authors, WWR should be between 20 and 35%. Additionally, a 5–10 cm layer of thermal insulation should be placed to an existing building's exterior in order to optimize the effectiveness of WWR [20].

The authors Chiesa et al. developed an algorithm that optimizes an office building's WWR during the early stages of design in order to reduce anticipated energy requirements for lighting, heating, and cooling in order to meet the Passive House concept's requirements. The strategy was used in two locations: 1.) Helsinki, which experiences severe winters; 2.) Turin, which has a moderate climate, and and is located in the wider Mediterranean region. The authors point out that an ideal WWR value can be obtained for both locations around 30% based on the outcomes of simulations run at constant occupation rates [21].

The study by Ashrafian and Moazzen investigated the effects of various WWR combinations on the comfort of occupants and the energy requirements of a classroom. In Eskisehir, Turkey, a standard school building intended to be built was chosen as the case study building. The findings indicate that while selecting a suitable design can reduce electricity usage by 15–18%, it can only lower the energy needed for heating by 8.5%. Additionally, although a 50% glazing ratio yields the best results, performance was found to be comparable with a 40% glazing ratio [16].

The studies that were examined highlighted how important it is to maximize WWR in order to improve occupant comfort and energy efficiency. Various techniques were used to identify the best WWR configurations, including the use of software tools such as GenOpt. Research carried out in a variety of climes demonstrated the universal significance of WWR where the recommended optimal WWR values for different building types and climates were in the range of 30% to 50%. Finally, the analyzed research highlighted how multidisciplinary sustainable building design is and how important it is to give careful thought to WWR in order to create comfortable and energy-efficient environments in a variety of settings.

3. Methodology

In Osijek-Baranja County, 187 elementary and high schools were the subject of the case study. The Energy Management Information System (EMIS) database, an online program for tracking and analyzing water and energy use data in public sector buildings, provided the data that was used in the analysis. The application is a necessary tool for systematic energy management in the public sector since it gives a clear overview and control over energy use in all buildings owned by the public sector. Numerous energy performance calculations, analyses, continuous monitoring, and energy usage control are made possible by the data in EMIS [22].

4. Discussion and results

The distribution and variability of the WWR variable are explained by the descriptive statistics analysis shown in Table 1. The mean WWR, or average ratio of window area to wall area in the dataset, is determined to be approximately 23.72% with a valid sample size of 187 data points. There appears to be a tendency for the distribution of WWR to be slightly tilted towards lower values, as indicated by the slightly lower median value of approximately 20.51%, which represents the middle value when all data points are sorted in ascending order

Tab. 1. WWR Descriptive statistics.

Variable name	Valid N	Mean	Median	Mode	Freq. of Mode	Min	Max	Lower Quartile	Upper Quartile	Var.	Std.Dev.	Coef.Var
WWR [%]	187	23,72	20,51	20,00	18	5,67	78,5	14,34	28,49	160,81	12,68	53,44

The observed value that occurs the most frequently, or the mode, is 20.00%. This value closely resembles the median, suggesting that it is a fairly common occurrence within the sample. It's interesting to notice, though, that this mode only occurs 18 times, indicating some distributional diversity. There is a significant variation in WWR values, from a minimum of 5,67% to a maximum of 78,5%. This large range suggests that the buildings or structures included in the sample have quite different window-to-wall ratios. The quartiles provide additional insight on the WWR distribution. A quarter of the data points have a WWR below this figure, according to the calculation of the lower quartile, or the 25th percentile, which is approximately 14.34%. On the other hand, three-quarters of the data points have a WWR below this figure, according to the top quartile, which represents the 75th percentile and is approximately 28.49%. With a variance of 160.81, which measures how widely apart data points are from the mean, the dataset's WWR values show considerable variability. The dispersion of WWR values is further highlighted by the standard deviation, which calculates the average deviation of data points from the mean and is 12.68%. Lastly, the percentage-based coefficient of variation offers an indication of the relative variability in WWR, showing that the standard deviation is responsible for about 53.44% of the mean WWR. This points to a moderate degree of variation from the mean.

Further analysis revealed a strong positive correlation between the WWR and the average 10-year cooling energy consumption, with a Pearson correlation coefficient of 0,704 (Table 2). This suggests that as the WWR increases, there tends to be a corresponding increase in cooling energy consumption. Buildings with higher WWR values often allow more solar heat gain through expansive glazing, necessitating increased cooling to maintain comfortable indoor temperatures. This correlation emphasizes the significant influence of architectural design on cooling energy demands in educational buildings. Additionally, it has been stated that the European air conditioning market has grown by 8.7% over the past ten years, particularly in Mediterranean nations, as a result of the widespread use of glass in office building facades [23, 24].

Tab. 2. Correlation matrix of WWR and energy consumptions.

Variable	Correlations (WWR) Marked correlations are significant at p < ,05000 N=187 (Casewise deletion of missing data)		
	Overall average 10 year heating energy consumption [kWh/a]	Average 10 year heating energy consumption [kWh/a]	Average 10 year cooling energy consumption [kWh/a]
WWR [%]	0,626023	0,569733	0,703614

On the other hand, a slightly weaker and moderate positive correlation was observed between WWR and average 10-year heating energy consumption, with a Pearson correlation coefficient of 0,570. Although still significant, this correlation indicates that while there is a tendency for heating energy consumption to increase with higher WWR values, other factors such as insulation levels and heating system efficiency may also play substantial roles in determining heating demands. Nonetheless, this correlation highlights the importance of considering WWR in energy-efficient building design, particularly in addressing both cooling and heating energy requirements.

5. Conclusion

These findings of this analysis highlight the complex relationship between WWR and energy consumption in educational buildings, which emphasizes the necessity of making careful design choices to maximize thermal comfort and energy efficiency. To ensure comfortable indoor settings conducive to learning, design interventions that carefully balance WWR with insulation, shading, and HVAC system efficiency can assist in minimizing energy use. Overall, the analysis offers valuable insights into the distribution, variability, and central tendency of WWR within the dataset, which can inform further research or decision-making processes related to building design or energy efficiency considerations. With its hot, dry summers, Croatia is a country where cooling is especially important. Due to solar heat gain, schools with large glass facades or windows may have higher inside temperatures. As a result, air conditioning systems are frequently used to keep staff and students comfortable. The use of air conditioning in schools can significantly increase energy prices, which raises operational costs and has an adverse effect on the environment. Furthermore, higher energy use for cooling increases carbon emissions, which increases the environmental impact of educational institutions. This research contributes to the body of knowledge on energy-efficient building design and provides valuable insights for policymakers, designers, and educators striving to reduce the environmental footprint of educational facilities.

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