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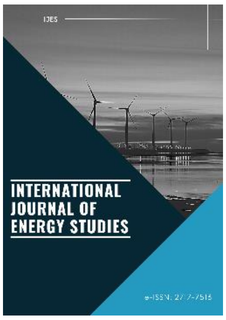

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Calculating the optimum window-to-wall ratio according to daylight factor and thermal performance in Mediterranean climate

Pooya Lotfabadi[a*]
[a] *Faculty of Architecture, Final International University, ORCID:0000-0002-4542-1007*
*(*Corresponding Author: pooya.lotfabadi@gmail.com/ pooya.lotfabadi@final.edu.tr)*

Highlights

- The common dilemma in the field of energy is the need of a systematic procedure to determine the optimum system and the optimum mode of operation in building sector.
- It is the research and case report, concentrated on the concepts and knowledge system of optimization and tries to propose a simple strategy to evaluate the best performance of different window-to-wall ratios for hot and humid climates.
- This study carries out a field measurement of various opening sizes in the case study in order to make a satisfactory situation both from energy efficiency and visual comfort considerations.

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ABSTRACT

Energy is a significant part of socio-economic development of modern societies. Increasing fossil fuel consumption is almost the main source of energy throughout the world. Thus, it is essential to search for more sustainable alternatives or a method to decrease this huge amount of usage. On the other hand, the building industry is known as one of the biggest energy consumers. Among building energy efficiency measures, openings are playing a key role in declining energy consumption, especially in the hot summers of Cyprus. Therefore, this study carries out a field measurement of various opening sizes in the case study in order to make a satisfactory situation both from energy efficiency and visual comfort considerations. Meanwhile, a studio in a faculty of architecture, Famagusta, North Cyprus, has been selected as an experimental examination to show the effectiveness of the method. In order to analyze its energy performance, the calculation simplified method is chosen. Outcomes are intended to illustrate the benefits of the calculation method and to authorize opening size comparisons to display the differences in energy conservation measures inherent in the various compliance methods allowable by the regulations. Finally, the results obviously display that by decreasing the window-to-wall ratio, the heat loss significantly reduces. But, by considering the daylight factor (DF) in the standard defined range and applying 750lux as an essential lighting requirement for the studio, finding the minimum WWR seems more meaningful. Therefore, according to the mentioned criteria in this special case, an optimum amount of WWR can be considered in the range of 10 to 20%, which gives architects some flexibility to apply in their designs.

Keywords: Visual comfort, Thermal comfort, Energy efficiency, Window-to-wall ratio.

1. INTRODUCTION

Energy consumption is an essential factor affecting architecture. This issue gained even more attention after the 1970s global oil crisis, as reducing dependency on fossil fuels became a priority [1, 2]. Harvesting the maximum advantages of any applied energy source is also a key issue that directly affects energy consumption. Therefore, benefiting from renewable energies has become an important way to achieve indoor thermal comfort [3]. The most important types of renewable energy sources, such as wind, solar, and geothermal energy, are suitable for application in almost all parts of the world. Undoubtedly, solar radiation, as a type of sustainable energy source, has a greater impact on human living conditions than other sources [4]. This type of renewable energy source can provide sufficient illuminance for building dwellers while also heating the space.

Designing buildings while considering visual and thermal comfort parameters is a crucial part of an architect's profession. It requires analyzing various aspects of building components. In the case of educational buildings, this aspect has become more sensitive. Visual comfort is one of the most important factors in educational spaces as it has a direct impact on pupils' health, well-being, and learning outcomes. Studying in a class with poor or excessive illumination levels can cause serious negative effects on students' health such as eye diseases, headaches, early fatigue, nausea, drowsiness, and so on [5]. Therefore, this topic should receive more attention in educational spaces where students are going to spend extended periods, and restrictions on physical activities are common, especially in studio-type spaces [6].

In this case, education in the field of architecture can be classified in the same category. The duration of studio activities for architecture students is often longer than that of traditional theory classes [7]. Therefore, it is essential to examine the level of luminance in workshop or studio classes, which can be achieved through daylighting, to determine whether it falls within the acceptable range of educational space standards. Furthermore, the transparency ratio of the space can be optimized to balance visual and thermal comfort conditions, as it has a direct effect on the space heating and cooling load.

There are many simulation software programs available to analyze and evaluate the potential benefits of daylighting in buildings [8-10]. However, these methods can be time-consuming and require a lengthy input process for designers. Some models have been developed to predict energy savings for different types of opening designs, but they require several calculations and are only applicable to specific sites or climate zones [11, 12]. Therefore, the aim of this study is to introduce a simple and basic analysis method that can be used as a pre-design tool to determine the potential of daylighting in optimizing visual parameters related to thermal energy consumption in educational buildings.

To achieve the goal of evaluating the potential of daylighting in optimizing visual parameters associated with thermal energy consumption in educational buildings, this study has two main parts. The first part is based on a theoretical approach, which is supported by previous literature and documentary research. The second part involves evaluating the energy performance of a case study, which is a studio located in the Faculty of Architecture at EMU in Famagusta, North Cyprus. A simplified calculation method has been chosen to evaluate the energy performance of the case study and its lighting situation. The aim is to propose the optimum amount of window-to-wall ratio (WWR) for the case study.

Moreover, in case of achieving visual comfort, the case study should be protected from direct solar radiations, when it is above a certain density (often $50W/m^2$) or even when the Daylight Glare Probability (DGP) at the space becomes ‘disturbing’ (>40%) [13]. However, in the case study, which is a studio in the faculty of architecture, it is almost impossible to predict the pupils’ positions and tasks, and on the other hand, the studio furniture may be organized in so many various positions as well.

2. HISTORICAL AND THEORETICAL BACKGROUND KNOWLEDGE OF THE STUDY

This part concentrates on the theoretical background and historical development of available literature about the subject of this research. Generally, in the field of saving energy and reducing greenhouse gasses (GHG) emission, a big amount of current knowledge and studies focuses on developing existing buildings’ performance through energy retrofits [14, 15]. In other words, to improve building energy performance and reduce greenhouse gas (GHG) emissions, numerous studies have concentrated on assessing and enhancing the performance of existing buildings through energy retrofits.

According to Hoppe and Martinac, individuals in developed nations spend nearly 90% of their time indoors, underscoring the importance of thermal and visual comfort, indoor air quality, and air conditioning systems [16, 17]. HVAC systems are frequently used for heating, cooling, and ventilation to guarantee that occupants experience comfortable temperatures and healthy air quality. However, despite these attempts, many studies have shown that occupants are frequently dissatisfied with the thermal comfort and indoor environment [18, 19].

Numerous studies have revealed a strong correlation between the indoor thermal environment and buildings' energy consumption. Also, some researchers have concentrated on the direct connection between human thermal comfort and energy usage [17, 20-24]. For instance; Holz et al. used DOE-2 simulation software to analyze the relationship between building energy usage, human comfort, and three energy conservation measures [25]. They conducted a sensitivity analysis of six comfort factors and found that human thermal comfort is significantly affected by mean air temperature, radiant temperature, occupants' clothing level, and activity level [26-28].

To conduct a more comprehensive analysis, building energy performance assessments should incorporate thermal comfort evaluation parameters. For instance, Poirazis et al. established a minimum acceptable thermal comfort level for configuring a specific building's energy performance in 2008 [29]. Additionally, Nielsen et al. (2011) evaluated the internal set point temperature related to the expected level of comfort conditions in the EN15251 2007 standard [30, 31]. Various applications, such as designing HVAC systems for buildings based on U-values of the building components, require modeling the thermal response of the human body under different personal and environmental conditions. Since the 1970s, researchers have designed and developed many human thermal response models based on the energy balance equations for the human body. Two primary models that are often used to evaluate thermal sensation are Fanger's PMV-PPD model and Gagge's two-node transient model [32]. Stolwijk developed the first multi-segmented human body model, and since then, several improved multi-segment models have been developed, such as the Berkeley Comfort Model [33-36], AUB model [37, 38], and the models discussed by Tanabe et al. [39], Fiala et al. [40], Yi et al. [41], Fengzhi and Yi [42], Yigit [43], and Kaynakli et al. [19].

Following Fanger's proposal, the evaluation of indoor thermal comfort primarily relies on his method, which involves measuring the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices. This method has been accepted by various building regulations and standards, including ISO 7730 and ASHRAE 55 [44-47]. When PMV falls between -0.5 and 0.5, and PPD is less than 10%, the thermal comfort situation is considered acceptable. However, different regulations classify comfort situations into various groups, such as A, B, and C, in European regulations [46, 48].

The US standard provides an alternative way to define acceptable thermal conditions in buildings with natural ventilation systems (NVBs) using a graph and indoor comfort temperatures, with possible limits for 80% and 90% thermal acceptability. This method is applicable in spaces with operable windows, no mechanical cooling systems, and where occupants can adjust their clothing. However, this method may not be suitable if a mechanical system is used to ventilate the space. The recommended temperature limits are monthly mean outdoor temperatures below 10°C or above 33.5°C. Similarly, prEN 15 251:2005(E) also suggests the use of the graphic method to determine thermal acceptability in NVBs [45, 46, 49].

In addition, researchers have explored the potential for adaptation as a means of reducing building energy consumption [50, 51]. For example, the European Technical Standard [31] has suggested an approach for buildings without mechanical heating and cooling systems that takes into account adaptation possibilities. Other researchers have developed scenarios for achieving thermal comfort by comparing adaptive models with the PMV model based on Fanger's steady-state model [52]. Van Hoof and Hensen (2007) compared the comfort ranges offered by adaptive and non-adaptive models and proposed that in the climate of Cyprus, adaptive models are not sufficient [53, 54].

Thermal sensation indices such as PMV, ET, and SET are commonly used to evaluate thermal comfort in uniform and stable environments. However, little research has been done to understand the relationship between overall thermal sensation and overall thermal comfort in non-uniform or dynamic environments [27, 28, 55-59]. Zhang proposed an overall thermal comfort model based on local thermal comfort conditions and overall thermal sensation [60], while Andamon analyzed the relationship between overall thermal sensation, comfort, and acceptability in both uniform and non-uniform conditions. Although Andamon found that dynamic thermal sensation had a strong impact on thermal comfort in non-uniform conditions, no conclusive results were obtained for dynamic conditions [61, 62].

Furthermore, numerous studies conducted in real-world settings have demonstrated that the Fanger theory, which explains thermal comfort in steady-state conditions, does not apply to buildings that operate without artificial heating or cooling, not only in warm climates but also in moderate ones. The reason for this is that this theory did not account for the way people's behavior changes and their preferences and expectations gradually adapt to the surrounding environment [62]. As a result, this study utilized the U-value analysis method to determine thermal comfort in the case study. It is worth noting that this method has been employed since the 1960s and is regularly revised and updated in various building codes and regulations.

This simplified calculation method has been accredited and promoted to evaluate the potential decrease in total annual heating and lighting energy consumption in educational buildings. The methodology considers the window size, the glazing type, the building geometry and etc. Various parametric analysis shows that by adjusting the coefficients of the method, it can be applicable for commonly used thermal and natural lighting control strategies and settings [63].

In contrast, the building industry has identified lighting as the primary consumer of electricity compared to all other end uses [64]. Due to the large volume of electricity consumed and the inefficient conversion process from resources to the building site, lighting is the largest contributor to carbon emissions (amounting to 554 million metric tons of CO_2) and other environmental consequences in the construction sector. Additionally, the conversion of electricity to useful light is among the least efficient energy conversion methods available [65].

Since the late 1990s, the appropriate quality of lighting has been described as a combination of human needs, environmental and economic factors, and architectural design. The ideal lighting system should not only provide the necessary level of visual performance but also enhance the spatial appearance, contribute to well-being, and ensure safety [66]. However, with the increasing awareness of the role of light in human health, the concept of lighting quality has become more intricate, and people's attitudes toward the subject have changed [67]. Recent studies have focused on establishing the relationship between human health, performance, and environmental lighting, with encouraging outcomes. It is now widely acknowledged that inadequate or insufficient exposure to light can disrupt normal human rhythms, which can have adverse effects on safety, health, and performance [68, 69].

Nowadays, lighting in interior design is generally based on the application of the European Standard EN 12464-1, which refers particularly to systems of electric lighting [70]. Adapting to this standard can be beneficial in terms of sizing and locating lighting systems to ensure the required mean-maintained illuminance values on task areas and their immediate surroundings for various working activities [69]. In addition, apart from, using simulation software, promoted the analysis of moveable blinds in the case of assessing its effect on some visual comfort parameters, such as daylight factor (DF) or illuminance value [13, 70].

For instance, from the lighting point of view, the automation control scheme design has been proposed by assessing large transparent surfaces, which had the capability of gaining extreme solar radiation. On the other hand, this parameter can increment the Daylight Factor (DF) that is led to develop the level of visual comfort by enhancing the amount of the Sky Component (SC) with strategies like enlarging the size of openings, enhancing the Internally Reflected Component (IRC) with using light color in interior building surfaces and increasing the Externally Reflected Component (ERC) with benefitting from lighter colors in building [71].

In addition, it is important to achieve a uniform illuminance distribution with sufficient uniformity ratios in the immediate surroundings and task areas. The issue of glare is addressed using the Unified Glare Rating (UGR) approach. Typically, the glare values are analyzed by luminaire factors presented in tables, which are a function of room dimensions, the position of luminaries in relation to work positions, and symmetric conditions [69].

In contrast, daylighting in educational buildings during work hours is typically evaluated separately and is often still assessed using the Daylight Factor (DF), despite the introduction of new factors and parameters such as Useful Daylight Illuminances (UDI) [72]. Additionally, although glare indexes have been widely used in scientific research, there is no established standard for daylight glare ratings, and the Daylight Glare Index (DGI) has not been deemed authentic [73, 74]. Recent studies have focused on daylighting for its potential to save energy, which is emphasized by the European Code “Energy performance of buildings energy requirements for lighting”. This code specifies the calculation and measurement to be beneficial in assessing the amount of energy consumed by building lighting [28, 75].

Finally, as it was mentioned, there were several studies, which were based on indoor thermal comfort and visual comfort by considering different methods and criteria. They have also analyzed various parts of building structures and elements such as different types of glazing surfaces and shading devices. However, what can be considered a huge gap in the whole study, is evaluating indoor thermal comfort and visual comfort, simultaneously. Therefore, this study attempts to fill this gap by simply analyzing a case study, which will be more explained in upcoming parts.

3. RESEARCH METHODOLOGY

In general, this study is based on a theoretical approach that is supported by previous literature and analysis of the case study. The approach combines two main phases of data collection: qualitative and quantitative methods, which include calculations and a literature survey. The calculation part focuses on optimizing the building for thermal and visual comfort. Thermal insulation is crucial in achieving thermal comfort in the construction industry, as it can greatly reduce the transfer of heat between indoor and outdoor environments, leading to a significant decrease in the amount of energy needed for building heating and cooling. However, insulation is not limited to materials such as glass wool, rock wool, polystyrene, cellulose, and urethane foam, but also encompasses various designs and techniques that take into account the primary modes of heat transfer, including conduction, radiation, and convection [76].

Thermal resistance, which is based on building materials and/or insulation materials is defined by R-value, is the evaluation of a sample of the material's ability to reduce the heat transfer rate under specific test conditions. Thereby, it can be described as heat transfer per unit area per unit time, (Q_A) through the building materials or $R = {}^{\Delta T}/_{Q_A}$ (Eq. 1) [77]. The unit of thermal resistance is defined as R-value. This indicates a unit value of any type of particular material. It is attained by dividing the thickness of the material by the thermal conductivity. By dividing the unit thermal resistance, not the unit resistance, by the area of the material, the thermal resistance of an entire section of material is achieved. The R-value is the reciprocalthe of the U-value. It should also be mentioned that in case of measuring the R-value in multi-layer surfaces, this value can be considered as the sum up of the various layers R-value, which is calculated as follows;

$$\text{Resistivity } (\mathbf{R}) = \frac{\text{Material thickness } (\mathbf{d})}{\text{Thermal conductivity coefficient } (\mathbf{k})} \qquad \text{(Eq. 2) [78]}$$

The 'U-value' or the so-called 'U-factor', is described as the total amount of heat transfer coefficient, which illustrates the building's elements performance of heat transfer measured in watts, through 1m² of a building surface divided by the temperature differences across the structure. It is also explicit in watts per square meters Kelvin (W/m²K). Therefore, the much higher amounts of U-value of the buildings' façades, displays the lowest thermal performance of the building and also much heat transfers among surfaces. As the U-factor is a way of predicting and understanding the complex behavior of the whole construction elements, apart from relying on the individual material properties, it is very beneficial.

$$U = \frac{1}{R} = \frac{Q_A}{\Delta T} \qquad \text{(Eq. 3) [77]}$$

In the mentioned formula, the SI units of U, which is the inverted form of ΣR is W/(m^{2}K) and this unit in the imperial system is BTU/(h °F ft^2) [77]. U-value is mainly used in order to explain windows insulation value and thermal effectiveness, on the other hand, R-value is a term, which is used to describe insulation properties of the other parts of a building envelope including walls, roofs, and floors. However, it is common to only benefit from U-Value/ U-Factor to evaluate the entire building's components simultaneously. Finally, the U-value is beneficial in order to calculate the heat loss according to the following formula;

$$\text{Heat Value} = \text{Area} \times \text{U-value} \times \Delta \text{T} \qquad \text{(Eq. 4) [78]}$$

Lighting is indispensable for visual performances and can also affect the level of attention. Sufficient light quality plays a noteworthy role in the physical and psychological processes of humans. The results of previous studies display that pupils' performance is enhanced by creating a proper visual environment [79, 80]. Apart from this issue, electric lighting energy usage is another important criterion in educational buildings. However, as architectural studios are multi-functional spaces and their depth are almost high, it is somehow difficult to light them only with the aid of natural lighting. Thus, by benefitting from such luminaires, combined with both national and artificial lighting, which can lead to direct light on the work areas and also an indirect light towards the ceiling and walls, a varying and appropriate concentration of light is distributed throughout the interior space.

In order to create a proper lighting concept, it is necessary to have sufficient knowledge about the various functions and tasks that happen in the classroom/ studio. This is due to the fact that each function requires special light conditions. During the day, various visual tasks take place in a studio. Thus, it is important to consider high requirements for light quality. Both pupils and instructors have taken advantage of the lighting, supporting them ideally, while doing their activities. Meanwhile, the point here is how to consider the human being's needs as a focal point and simultaneously, avoid neglecting the energy efficiency principles. Therefore, the next table illustrates the European norm EN 12464-1 illuminance requirements for school buildings.

Table 1. Daylighting minimum requirements for educational building

	Space Function	Minimum Requirements	
		Illuminance	**Daylight Factor**
1	Classrooms	300 lux	~ 2%
2	Tutorial rooms	300 lux	~ 2%
3	Lecture hall	300 lux	~ 2%
4	Blackboard	300 lux	~ 2%
5	Art rooms in art schools	750 lux	~ 5%
6	Technical drawing rooms	750 lux	~ 5%
7	Circulation areas, corridors	100 lux	---

The luminance and contrast must meet certain criteria: the luminance should not exceed 3000 cd/m² and the contrast in the (wide) visual field should be less than 1:30. However, according to the research limitations, in this research, due to the mentioned standards, the specific amount of 750 lux is considered as the minimum average of required illuminance to provide buildings' occupants a sense of well-being and allows them to perform their visual tasks in a studio.

As mentioned earlier, the daylight factor (DF) is the oldest metric used to evaluate the availability of daylight in studies. This parameter is often used to evaluate the efficiency of daylighting in buildings. DF is defined as the ratio of internal illuminance to the available illuminance on a horizontal plane from the entire unobstructed sky, under CIE standard overcast sky conditions. This value is expressed as a percentage. [81, 82].

$$\text{Daylight Factor (DF)} = \frac{Internalilluminance}{Externalilluminance} \times 100 \qquad \text{(Eq. 5)}$$

The daylight reaching any point inside a room is usually made up of three separate components as follows;

- Sky Component (SC),

- Externally Reflected Component (ERC),
- Internally Reflected Component (IRC).

In the early stages of designing a building, in order to determine the adequacy of daylight, the average DF can be used.

The average daylight factor calculation is mainly based on the split-flux principal theory, which is dividing the entering flux through the window over its lower parts of the room surface areas and total internal surface areas. In other words, by increasing the space floor size, which also leads to an increase in the internal surface areas, the value of the average DF will be decreased. Therefore, it is obvious that in a side-lit space, based on the sky component value, the maximum amount of DF can be reached near the fenestration elements [83].

$$\text{Average DF} = \frac{W}{A} \times \frac{T\theta}{(1-R^2)} \qquad \text{(Eq. 6) [83]}$$

Where, in the research case study, parameters can be defined as described in table 2;

Table 2. Average daylight factor calculation parameters

Parameters	Abbreviation	Unit	Amount	Description
The windows' area	W	m²	Changeable	---
The internal surfaces' total area	A	m²	330.75	---
The glass transmittance corrected for dirt	T	---	0.6	For double-glazed windows in clean environment
Visible sky angle from the center of the window	θ	°	90°	Without any obstructive element consideration
The average reflectance of area A	R	---	0.6	Considering light colored room surfaces

It should be mentioned that the amounts of the quantities like 'W, T, and R' are specified from the daylight codes and standards. Finally, this research involves the U-value, heating and cooling day temperature analysis in terms of case study thermal comfort evaluations. On the other hand, it considers daylight factor parameters in order to evaluate visual comfort. This simplified method of measurement has been accredited and promoted in order to measure the probable decrease in the overall annual heating and lighting energy usage in educational buildings. This approach considers the window size, the glazing type, the building geometry, etc. In this case, this method can be applied to widely used thermal and natural lighting control strategies and settings by changing the method's coefficients.

4. CASE STUDY ANALYSIS

The selected case study is in Famagusta, Turkish Republic of Northern Cyprus, which is a port and the 3rd largest city on the island. The city population is almost around 54,000 [84]. One of the main city infrastructure constructions is the Eastern Mediterranean University (EMU) complex, which has played a significant role in bringing the population together, after the 1974 crises. Thus, a studio (A10) in the Faculty of Architecture has been selected as a case study. This selection is because the studio is located on the first floor, which means that it is somehow protected with thermally controlled zones from all surfaces, except one, which is only lighted from the south direction.

The studio dimensions are 7m by 13.5m and the height of 3.5m. As it was mentioned this studio is only lit from one side, which is not too deep and can be considered as a proper dimension to gain natural light (Fig. 1). It is lit by two windows with a length of 3m, and the other 4m in the center, and the heights are 2.35m. Therefore, the total south surface gross area is 47.25m² and the total fenestration of this wall gross area is 23.5m². In other words, the mentioned measurements illustrate that the current window-to-wall ratio is approximately 49.7%. Also, it should be mentioned that this studio has been selected on the first floor to avoid any obstacles that may prevent natural light from entering the space at different times.

Faculty of Architecture Site Plan **First Floor Plan**

Figure 1. Case study (A10)

Based on building codes the Degree-days cooling and the degree-days heating are units in order to measure heating and cooling energy demands according to daily mean temperature deviations from the assumed comfortable baseline temperature, which is 18˚C for the average degree days for winters and 22˚C for summers. If the mean temperature passes the mentioned temperature, the cooling degree-days method will be applied and it is vice versa for heating degree-days.

Famagusta is located at 35°7'N and 33°55'E with an altitude of 25m above sea level. The Köppen system describes its climate as a hot Mediterranean/ dry-summer subtropical climate. The city experiences hot and dry summers due to subtropical high-pressure systems and rainy and moderate weather during the cold season because of the polar front. During the hot season, the average maximum temperature is around 33˚C, and during the cold season, the average minimum temperature is approximately 17˚C (Fig. 2). To maintain a comfortable indoor environment and protect it from the outdoor environment, the building needs to be adjusted with 1 heating degree-day and 11 cooling degree-days, highlighting the importance of protection during summers.

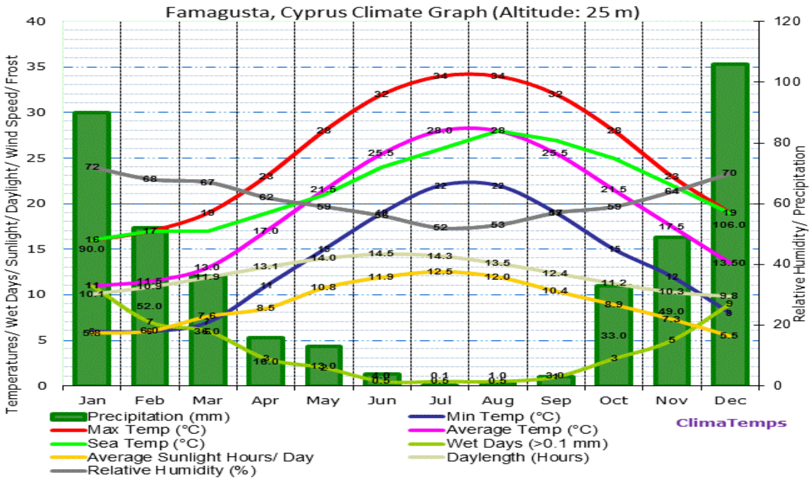


Figure 2. Famagusta climate graph [85]

In this case, after analyzing the initial requirements and climate conditions, according to (Eq. 2& 3), the building thermal conductivity analysis results have been presented in the following table;

Table 3. U-value calculation

Wall				
Material	**Thickness** (m)	**Thermal conductivity coefficient** (k) [70]	**R-Value** ($(m^2K)/W$)	**U-Value** ($W/(m^2K)$)
Inside Surface	----	----	0.12	
Plaster	0.005	0.17	0.03	
Cement	0.02	0.29	0.07	
Brick Block	0.15	0.86	0.17	
Cement	0.02	0.29	0.07	
Outside	----	----	0.06	
	Total		**0.52**	**1.92**
Window				
Single Layer Glass				**5.6** [77]

From the above table, the total R-value and accordingly the total U-value are separately achieved for both solid and transparent areas. As it was mentioned, the main aim of this study is to find the optimum amount of window-to-wall ratio. In other words, the building heat losses should be minimized. In this case, by considering the U-value as a constant unit and the temperature difference between inside and outside as a constant amount (11˚C critical cooling degree-day in summer), the only remaining variable is the surface area.

In this regard, a range of 10-90% WWR is considered as variables, which define the surface area and calculated separately for windows and solid areas and consequently as a total surface area, which can be used in (Eq. 4). As it was mentioned, ΔT is considered as 11˚C. Therefore, from the mentioned data, the amount of heat losses can be calculated for different window-to-wall ratios. The next table illustrates predicted various window-to-wall ratios for the A10 studio;

Table 4. Total amount of heat losses according to various window-to-wall ratios

Window-to-Wall Ratio and Fenestration Area

WWR	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%
Fenestration Area (m²)	4.72	7.09	9.45	11.81	14.17	16.54	18.90	21.26	23.62	25.99	28.35	30.71	33.07	35.44	37.80	40.16	42.52
Heat Losses (w)	291.06	436.56	582.12	727.62	873.18	1018.68	1164.24	1309.74	1455.3	1600.8	1746.36	1891.85	2037.42	2182.92	2328.48	2473.98	2619.54

Window-to-Wall Ratio and Solid Wall Area

WWR	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%
Solid Area (m²)	42.252	40.162	37.80	35.437	33.075	30.712	28.35	25.987	23.625	21.262	18.90	16.537	14.175	11.812	9.45	7.087	4.725
Heat Losses (w)	898.13	848.22	798.34	748.43	698.54	648.64	598.75	548.84	498.96	449.05	399.17	349.26	299.38	249.47	199.58	149.68	99.79

Total Amount of Heat Losses According to the Different Window-to-Wall Ratios

WWR	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%
Total Heat Losses (w)	1189.19	1284.78	1380.46	1476.05	1571.72	1667.22	1762.99	1858.58	1954.26	2049.85	2145.53	2241.11	2336.8	2432.39	2528.06	2623.66	2719.33

From the above table, it can be concluded that if the window-to-wall ratio (WWR) has declined as much as possible, the heat losses decrease simultaneously. However, as the case study is a studio in the faculty of architecture, decreasing heat loss and promoting thermal comfort is not the only matter. In educational spaces, benefiting from the maximum amount of daylighting is another important criterion. Thus, the amount of studio average daylight factor (DF) for different percentages of window-to-wall ratio has been calculated by the mentioned values and formula (Eq. 6) (table 2), and the results are presented as follows;

Table 5. Average daylight factor according to various window-to-wall ratio

Average Daylight Factor According to the Different Window-to-Wall Ratios

WWR	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%
Fenestration Area (m²)	4.72	7.09	9.45	11.81	14.17	16.54	18.90	21.26	23.62	25.99	28.35	30.71	33.07	35.44	37.80	40.16	42.52
Average DF (%)	4.22	6.33	8.44	10.55	12.66	14.68	16.87	18.99	21.09	23.21	25.31	27.43	29.53	31.65	33.75	35.86	37.97

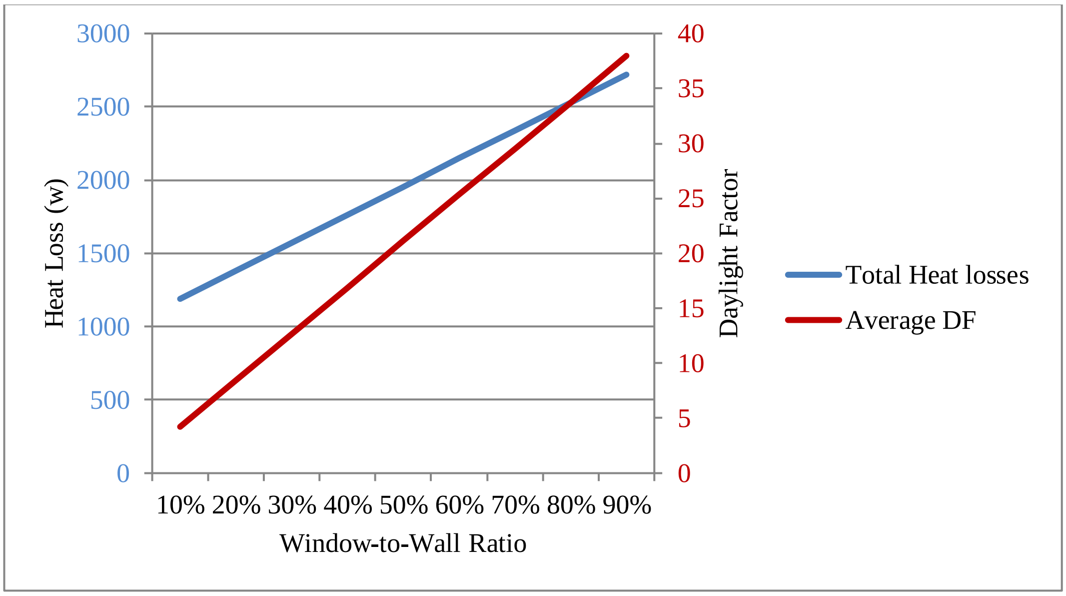
In the previous table calculation, the amount of the quantities such as 'W, T and R' are considered as constant units and specified from table 2 and just the area of the windows (W) contained as a variable. Furthermore, to evaluate the effect of daylight factor on the space illuminance quality, its various ranges describe as follows;

- DF≤ 2: The daylight amount is not adequate and artificial lighting support is required,
- 2≤ DF≤ 5: The daylight amount is almost adequate; however, artificial lighting may be required,
- DF> 5: The space is well-lighted and the daylight amount is adequate. In this case, artificial lighting is not essential, except at dawn and dusk times, however, the glare factor may lead to some visual problems [86].

Eventually, based on the mentioned data and analysis, it can be concluded that decreasing the window-to-wall ratio (WWR) in this specific hot and humid climate prevents space from overheating. In other words, decreasing the opening sizes lead to having more thermal comfort and simultaneously more energy saving. However, this is not the whole story. As an architect, we have to consider visual comfort as well. In this case, increasing the size of openings leads to more benefits from daylighting and as a result visual comfort and discomfort glare as well. As it was mentioned, the studio must be lit up to 750 lux. By applying this amount in equation 5, the acceptable range of DF can be achieved as follows; $(DF)=(750/10000)\times100=7.5$. Therefore, in order to control the discomfort glare without adding any shading devices, the average daylight factor should be limited to 7.5.

Therefore, the average daylight factor in the case study, which is an educational building and needs some special lighting considerations for technical drawings, modeling, and so on, should be in the approximate range of 2 to 7.5. Thus, based on the discomfort glare considerations, thermal and visual comfort criteria, the optimum range of the window-to-wall ratio (WWR) for this studio should be between 10 to 20%. These results can also be obtained from chart 1.

Chart 1. Building total heat losses and average daylight factor comparison



5. CONCLUSION

This study aims to analyze the opening sizes of educational buildings due to the importance of energy conservation in the building sector. As buildings consume a significant amount of energy, it is crucial to assess all aspects of the building design to achieve energy efficiency.

Based on the importance of energy conservation in the world and as buildings consume a significant amount of energy, it is crucial to assess all aspects of the building design. In this regard, the research attempts to evaluate the opening sizes of educational buildings. This is because apart from saving energy, benefiting from a sufficient amount of daylight is another important factor in designing these types of buildings. Natural lighting has both physical and psychological effects on pupils' behaviors. In other words, proper fenestration size in classrooms/ studios not only leads to saving a significant amount of energy by reducing heat loss but also can control the amount of daylighting and insufficient glare index.

Therefore, to achieve the mentioned purposes, this research evaluated an architectural studio as a case study. However, according to the research limitations, it uses the simplified calculation method to evaluate the window-to-wall ratio. Thus, firstly, according to literature and meteorological station statistics, 11˚C is considered a cooling-degree day for summer. Afterward, the total U-value for both solid and transparent areas has been calculated. Then, the researcher applied the mentioned values as a constant amount in the heat loss formula, in order to evaluate various windows-to-wall ratio (WWR) percentages.

Finally, the results obviously display that by reducing the window-to-wall ratio, the heat loss significantly reduces. But, by applying the 750 lux as an essential lighting requirement for the studio, finding the minimum WWR seems more meaningful. In this case, according to standards, to achieve the mentioned satisfying amount of lighting the average daylight factor should be approximately around a minimum of 2 to a maximum of 7.5. Therefore, between 10 to 20% WWR can be considered the optimum amount for this special case.

However, it should be mentioned that in this research as the simplified calculation method has been applied in the case study, it is not tried to give the precise percentage to expand for entire buildings in the hot and humid climate. It is tried to present the results as an optimum range and give architects more flexibility in their designs. Also, this is because of the fact that according to research limitations, several factors such as window frames and building structure have been neglected in the calculation. Therefore, this research is an attempt to display the importance of the subject and can be considered as a simple small-scale model that can be used as a sample in further studies. Eventually, there is a need for further work to validate, improve, and expand the proposed method for handling any building type and daylighting control approach, and potentially to anticipate the influence of daylighting on the total building energy consumption.

5.1. Limitation and Further Studies

It must be noted that the current study has some clear limitations. In the case study, which is a studio in the faculty of architecture, it is almost impossible to predict the pupils’ positions and tasks, and on the other hand, the studio furniture may be organized in so many various positions as well. Thus, the primary drawback of this approach is that the comfort parameters specified in technical standards do not take into consideration the amount of solar radiation that an individual is exposed to, particularly when transparent elements are involved. The author believes that this study is important because, according to the current energy crisis, it is the research and case report, concentrating on the concepts and knowledge system of optimization and tries to propose a simple strategy to evaluate the best performance of different window-to-wall ratios for hot and humid climates. The author hopes that this manuscript creates a paradigm for future studies on the evolution of these kinds of alternatives.

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DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Pooya Lotfabadi: Conceptualization; Formal analysis; Investigation; Methodology; Visualization; Roles/Writing - original draft; Writing - review & editing.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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