(05-042) - Optimization of window-to-wall ratio for different Koppen-Geiger classification: A review Study

Rafat Gigasari, Ali [1]; Cañada Soriano, Mar [1]; Aparicio-Fernández, Carolina [1]; Torner, Maria Eugenia [1]; Vivancos, José Luis [1]

[1] Universitat Politècnica de València

As a result of their function in heat exchange processes and solar gain management, window systems are commonly regarded as the most important component for energy efficiency. Thus, the window-to-wall ratio (WWR) of a building plays an important role in estimating total energy consumption (TEC). A variety of articles published between 2016 and 2022 have been analyzed to determine the optimal WWR by focusing on the TEC approach. This review investigates the optimal range for WWR based on minimizing total energy consumption for 46 cities with 10 different Köppen-Geiger classification (K-G) for 50 buildings , including office, residential, school, and hospital buildings. The suggested range for WWR is the minimum and maximum quantity for each orientation; so, a wide range of WWR is seen in the results.

Keywords: window-to-wall ratio; Total energy consumption; Köppen-Geiger classification; optimization; window orientation

Optimización de la relación ventana-pared para diferentes clasificaciones de Koppen-Geiger: Un estudio de revisión

Debido a su función en los procesos de intercambio de calor y gestión de la ganancia solar, los sistemas de ventanas suelen considerarse el componente más importante para la eficiencia energética. Así, la relación ventana-pared (WWR) de un edificio desempeña un papel importante en la estimación del consumo total de energía Se han analizado diversos artículos publicados entre 2016 y 2022 para determinar la WWR óptima centrándose en el enfoque del consumo total de energía. Esta revisión analiza el rango óptimo de WWR basado en la minimización del consumo total de energía para 46 ciudades con 10 clasificaciones Köppen-Geiger (K-G) diferentes para 50 edificios, incluyendo edificios de oficinas, residenciales, escuelas y hospitales. El rango sugerido para la relación ventana-pared de un edificio es la cantidad mínima y máxima para cada orientación, siendo por tanto este intervalo muy amplio.

Palabras clave: relación ventana-pared; consumo total de energía, clasificación Köppen-Geiger, orientación de ventana; optimización

Correspondencia: Carolina Aparicio Fernández, caap@upv.edu.es

1. Introduction:

The goal of this study is to find the optimum window-to-wall ratio (WWR) for each climate zone in terms of thermal energy consumption (TEC). Despite extensive efforts by international organizations, such as the EU Energy Efficiency Action Plans for 2020 and 2030, to improve energy efficiency in buildings (Torgal et al. 2014), the building sector remains a major consumer of global energy, accounting for about 36% of global energy consumption and 40% of greenhouse gas emissions (Dixit, Culp, and Fernández 2013). A significant portion of energy loss in buildings occurs through the building envelope, including the roof, sub-floor, doors, windows, and walls. According to the United States Energy Information Administration, 25% of heat loss in buildings is attributed to windows and doors, underscoring their critical role in a building's energy efficiency and thermal conditions (Mobaraki et al. 2022).

Given this context, the balance between opaque and transparent parts of a building facade emerges as a key factor influencing energy efficiency (Lee et al. 2013; Shen and Tzempelikos 2013). Specifically, windows, due to their lower insulation performance compared to other building materials, can significantly impact heat transfer and solar heat gain (Yeom et al. 2020a). Consequently, optimizing window dimensions is crucial for improving energy usage. Windows also play a vital role in influencing thermal comfort and the indoor environment (Awale and Uprety 2021). While solar heat can enhance thermal comfort during colder months and reduce heating needs, natural daylighting can lower energy consumption, boost productivity, and improve visual comfort (Peji, Djori, and Djeli 2014; Rautkylä 2012). Proper daylighting can further reduce electricity use for lighting (Nancy Ruck et al. 2010). The relationship between WWR, thermal/optical properties, and overall energy performance of windows is complex and influenced by climate and building orientation (Oranı, Bağlı, and Gerçekleştirilen 2020). According to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1, WWR should be maintained at or below 40% to minimize office building TEC (Berkes and Davidson-Hunt 2007).

Despite trends favoring increased window areas for visual contact and daylighting, identifying the optimal window-to-wall ratio is essential (Oliver et al. 2016). This varies by climate, requiring different WWR values, from high (up to 0.90 in Dsa and Dfa climates) to low (0.25 in Csa climates) (Goia 2016). Studies have shown that full glass facades can lead to high cooling loads (Gelesz and Reith 2015), and increasing WWR can significantly impact solar heat gain (Rana et al. 2020).This study aims to address the research gap concerning the optimal WWR for different climate zones to balance energy efficiency and thermal comfort. By investigating window sizes in Istanbul, a city with a temperate-humid climate, this research seeks to provide insights into optimal WWR values for different building orientations: north, south, west, and east (Yılmaz and Yılmaz 2020).

2. Methodology:

This study is a bibliographic analysis aimed at determining the optimal WWR for minimizing across various climate zones. The WWR is defined as the ratio of the total window glazing area to the entire facade area, which includes the surface area of opaque walls and windows (Rana et al. 2020). This relationship is mathematically represented in Equation 1:

$$\frac{\text{Total window glazing area}}{\text{Total exterior facade area (including wall and window)}} \times 100 \qquad (1)$$

2.1.Data Collection and Selection Criteria

Articles published between 2016 and 2022 were selected for this study to analyze the effects of WWR on TEC, which includes lighting, cooling, and heating energy consumption (Wen, Hiyama, and Koganei 2017). The selection was based on relevance to the research topic, focusing on studies that investigated the impact of WWR on TEC.

2.3.Objective

The primary objective of this research is to determine the optimal WWR range for 10 different Köppen-Geiger (K-G) climate classifications (Centre and Wetterdienst 2006) to minimize TEC.

2.4.Factors Considered

The selected articles considered a variety of factors influencing TEC, including:

Building Shape (Harmati and Magyar 2015)

Orientation (Pathirana, Rodrigo, and Halwatura 2019)

Glazing Type (Harmati and Magyar 2015)

Window Sunshade (Xue et al. 2019)

Building Height (Raj r Nair et al. 2014)

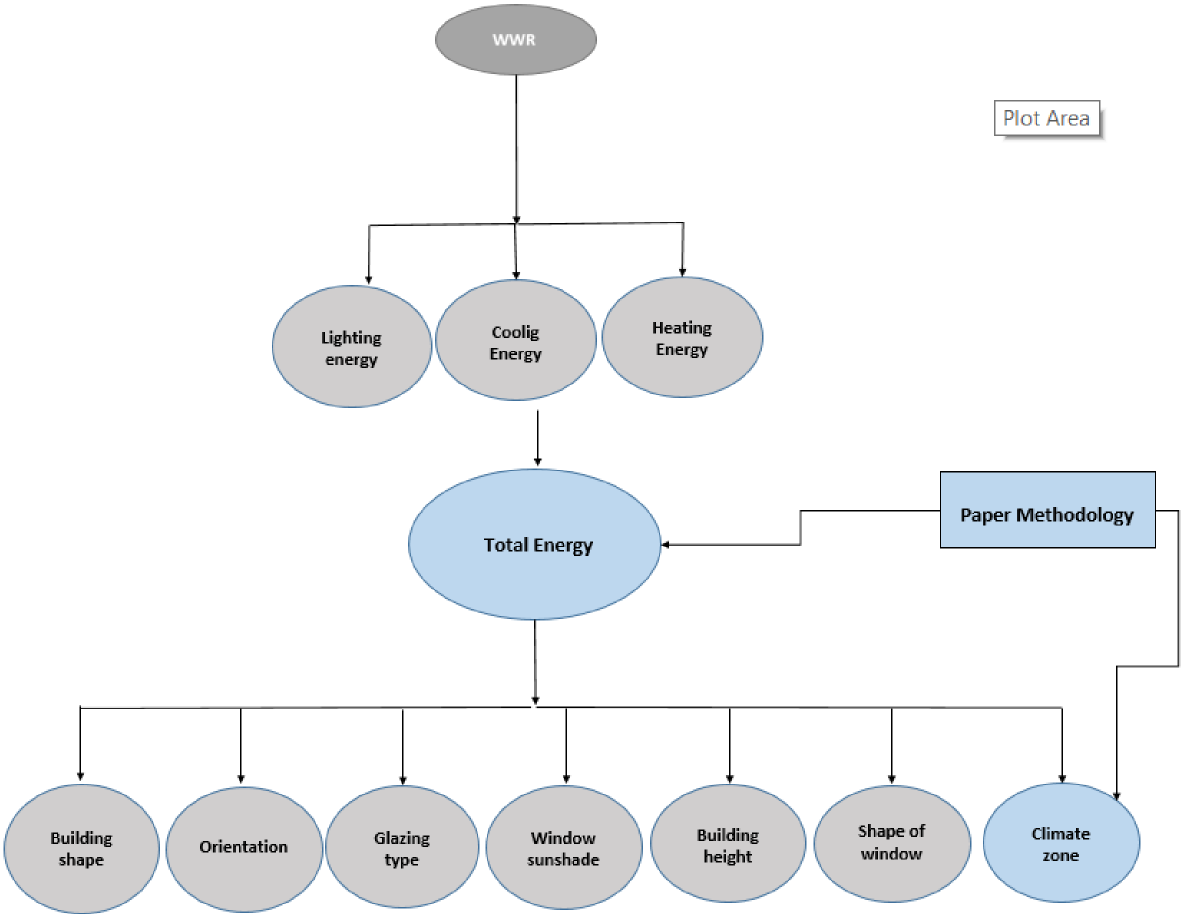
Window Shape (F. Motazedian 2019)

Climate Zone

These factors are visually summarized in Figure 1, which illustrates the selection criteria for the articles reviewed.

The analysis involves synthesizing findings from the selected studies to identify trends and optimal WWR values for each climate zone. The results provide guidelines for WWR that enhance energy efficiency while considering the influence of the aforementioned factors.

Figure 1 . Paper methodology



2.1 . Ten Climate Classification

Ten climate classifications considered in this study are described below research (Köppen-Geiger description)

Table.1. Presentation of different climate zones

Climate type	Description
Equatorial monsoon (Am)	A zone where the average monthly temperature is at least 18°C and the average annual cumulative precipitation is at least 25*(100-Pmin), where Pmin is the month with the least amount of precipitation, in millimeters.

Equatorial savannah with dry winter (Aw)	A zone where one winter month has less than 60 mm of precipitation and where the mean temperature for all twelve months is greater than or equal to 18°C.
Arid desert hot (Bhw)	A climate that is too dry and has a mean annual temperature of more than or equal to 18°C.
Warm temperate fully humid with hot summer (Cfa)	A climate in which the coldest month is warmer than -3°C but cooler than +18°C, and annual precipitation is generally constant. This climate is typically found between 25° and 35° latitude in the interior or on the east coast of continents .
Warm temperate fully humid with warm summer (Cfb)	A climate in which the coldest month is warmer than -3°C but cooler than +18°C, and annual precipitation is generally constant. This climate is typically found on the interior or eastern coast of continents, between 35° and 45° latitude.
Warm temperate with dry, hot summer (Csa)	The coldest month is warmer than -3°C but cooler than +18°C, and the summers are dry and hot. This climate is typically located on the western interiors of continents.
Warm temperate with dry winter and hot summer (Cwa)	A climate in which the coldest month is above -3°C but below +18°C, with dry winters. This climate is also characterized by hot, humid summers and is typically located on the interiors or east coasts of continents.
Snow with fully humid hot summer (Dfa)	A climate with at least one month with temperatures below -3°C, uniform precipitation throughout the year, and extremely hot summers. Typically, this climate occurs between 35° and 45° latitude.
Snow fully humid warm summer (Dfb)	A climate with at least one month with temperatures below -3°C and consistent precipitation throughout the year. This climate is typically found between 45° and 55° latitude, although it can extend as far north as 60° latitude.
Snow dry winter hot summer (Dwa)	A climate with at least one month with temperatures below -3°C, with dry winters and wet summers. This climate is typically found between 35° and 45° latitude in eastern Asia.

As shown in [table. 2], 46 cities and 50 buildings including office, residential, school, and hospital buildings were investigated to determine the optimal WWR. Furthermore, the suggested range for WWR is the minimum and maximum range for all orientations.

Table.2. 46 different cities for 10 climate zone

Location	Latitude	Longitude	Building type	(K-G)
Chittagong	22.35° N	91.78° E	Office	Am
Qionghai	19.25° N	110.47° E	Hotel	Am
Cox's Bazar	21.42° N	92.00° E	Office	Am
Sylhet	24.89° N	91.86° E	Office	Am
Dhaka	23.81° N	90.41° E	Office	Aw
Jessore	23.17° N	89.18° E	Office	Aw
Riyadh	24.71° N	46.67° E	Office - School	Bwh
Biskra	34.84° N	5.72° E	Residential- Office	Bwh
Taif	21.28° N	40.42° E	Villa	Bwh
Alexandria	31.20° N	29.91° E	Residential	Bwh
Cairo	30.04° N	31.23° E	Residential	Bwh
Minya	28.08° N	30.76° E	Residential	Bwh
Asyut	27.17° N	31.18° E	Residential	Bwh
Tokyo	35.67° N	139.65° E	Office	Cfa
Naha	26.21° N	127.67° E	Office	Cfa
Rasht	37.27° N	49.59° E	Office	Cfa
Messina	38.19° N	15.55° E	Office	Cfa
Naples	40.85° N	14.26° E	Office	Cfa
Rome	41.90° N	12.49° E	Office-Office	Cfa
Florence	43.76° N	11.25° E	Office	Cfa
Sydney	33.86° S	151.20° E	Office	Cfa
Shanghai	31.23° N	121.47° E	Residential	Cfa
Nanjing	32.05° N	118.79° E	Villa	Cfa
Delf	52.01° N	4.35° E	Office	Cfb
Potenza	40.64° N	15.80° E	Office	Cfb
Amsterdam	52.36° N	4.90° E	Office	Cfb
Frankfurt	50.11° N	8.68° E	Office	Cfb
Tehran	35.72° N	51.33° E	School	Csa
Lecce	40.35° N	18.17° E	Office	Csa
Constantine	36.35° N	6.63° E	Office	Csa
Izmir	38.42° N	27.14° E	Office Room	Csa
Athens	37.98° N	23.72° E	Office-Office	Csa
Tianjin	39.08° N	117.19° E	Office	Cwa
Bogra	24.84° N	89.37° E	Office	Cwa
Rangpur	25.74° N	89.27° E	Office	Cwa

Kathmandu	27.71° N	85.32° E	Office	Cwa
Perugia	43.11° N	12.39° E	Office	Dfa
Udine	46.07° N	13.23° E	Office	Dfa
Milan	45.46° N	9.19° E	Office	Dfa
Piacenza	45.05° N	9.69° E	Office	Dfa
Turin	45.07° N	7.68° E	Office	Dfb
Bolzano	46.49° N	11.35° E	Office	Dfb
Oslo	59.91° N	10.75° E	Office	Dfb
Sapporo	43.06° N	141.35° E	Office	Dfb
Incheon	37.45° N	126.70° E	Office	Dwa
Shengyang	41.80° N	123.43° E	Residential	Dwa

3. Results:

3.1.Equatorial Monsoon (Am)

Chittagong, Cox's Bazar, Sylhet (Bangladesh) [Fig 2]

- Findings: WWR: 20-30% for Chittagong, Sylhet, Dhaka, Jessore, Bogra, Rangpur; 10-20% for Cox's Bazar. Determined through shading, orientation, and thermal analysis. (Rana et al 2020)

- TEC Implications: Optimal WWR range identified for air-conditioned office buildings to minimize TEC.

Qionghai (China) [Fig 2]

- Findings: WWR: 40-60% for a 3-story hotel building. Workflow integrates daylighting and TEC optimization. (Xue et al 2019)

- TEC Implications: Sunshade integration with WWR enhances energy efficiency via daylighting strategies.

3.2. Arid Desert Hot (Bwh)

Taif (Saudi Arabia) [Fig 2]

- Findings: Optimal WWR: 20-30%. Below 20% increases cooling demand. (Alwetaishi 2022)

- TEC Implications: Balancing WWR crucial to avoid excessive cooling demand.

Riyadh (Saudi Arabia) [Fig 2]

- Findings: Optimal WWR: 20-30%. Balances daylight availability and energy load. (Asfour 2020)

- TEC Implications: Compromise necessary for energy-efficient design in arid climates.

Bisakra and Constantine (Algeria) [Fig 2]

- Findings: Optimal WWR: 40-50%. Key criterion for reducing energy load. (Badeche and Bouchahm 2020)

- TEC Implications: Orientation, shading, and WWR optimization crucial for TEC reduction.

Egyptian Cities (Minya, Cairo, Alexandria, Asyut) [Fig 2]

- Findings: Optimal WWR: 20-30% (Cairo, Alexandria, Asyut); 20-25% (Minya). (Imene Luhmar et al. 2022)

- TEC Implications: Similar TEC outcomes for different orientations at specified WWR.

3.3. Warm Temperate (Cfa, Cfb, Csa, Cwa)

Japanese Cities (Tokyo, Naha, Sapporo) [Fig 2]

- Findings: Optimal WWR: 40-50% (Naha); 50-60% (Tokyo, Sapporo). Factors: lighting, climate, orientation. (Wen et al. 2017)

- TEC Implications: Considerable impact of factors on optimal WWR for energy efficiency.

Rasht (Iran) [Fig 2]

- Findings: Optimal WWR: 15-20%. High TEC for WWR > 20%. (Hadiseh et al. 2019)

- TEC Implications: Importance of considering TEC when determining WWR for office buildings.

Italian Cities [Fig 2]

- Findings: Optimal WWR varies across cities. Smart shading impacts WWR. (Marino et al. 2017)

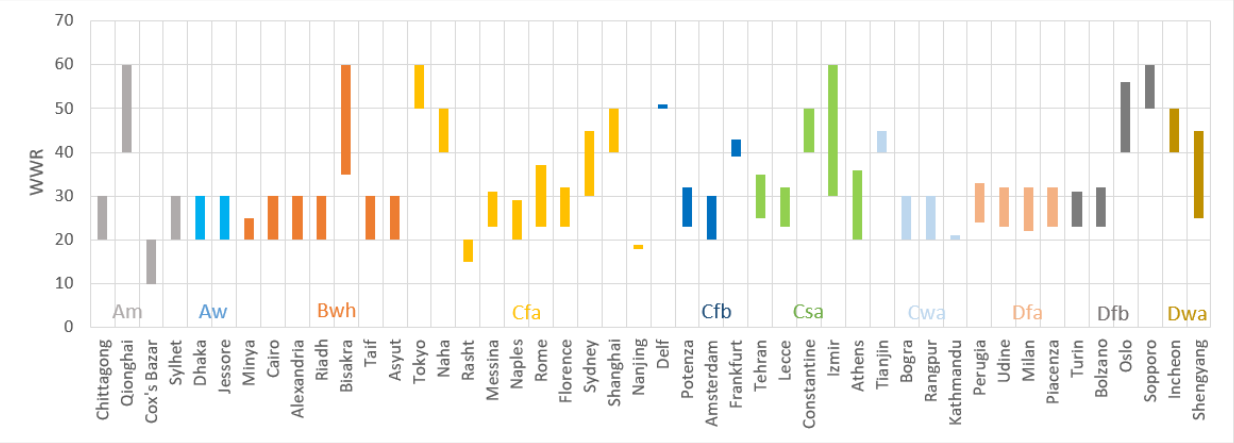
- TEC Implications: City-specific recommendations for tailored WWR optimization.

Dutch and Australian Cities (Amsterdam, Sydney) [Fig 2]

- Findings: Optimal WWR: 30-45% (Sydney); 20-30% (Amsterdam). Geometric factors considered. (Babak Raji et al. 2017)

- TEC Implications: Local climate and building characteristics crucial for WWR determination.

Figure 2. WWR range for all cities and related K-G



the current paper suggests a range for each climate, which includes minimum and maximum amounts for all building orientations. Am= 10-60%, Aw= 20-30%, Bhw= 20-60%, Cfa=15-60% Cfa=20-50%, Csa=20=60%, Cwa=20-45%, Dfa=22-33%, Dfb=23-60% and Dwa=10-60% [Fig 3].

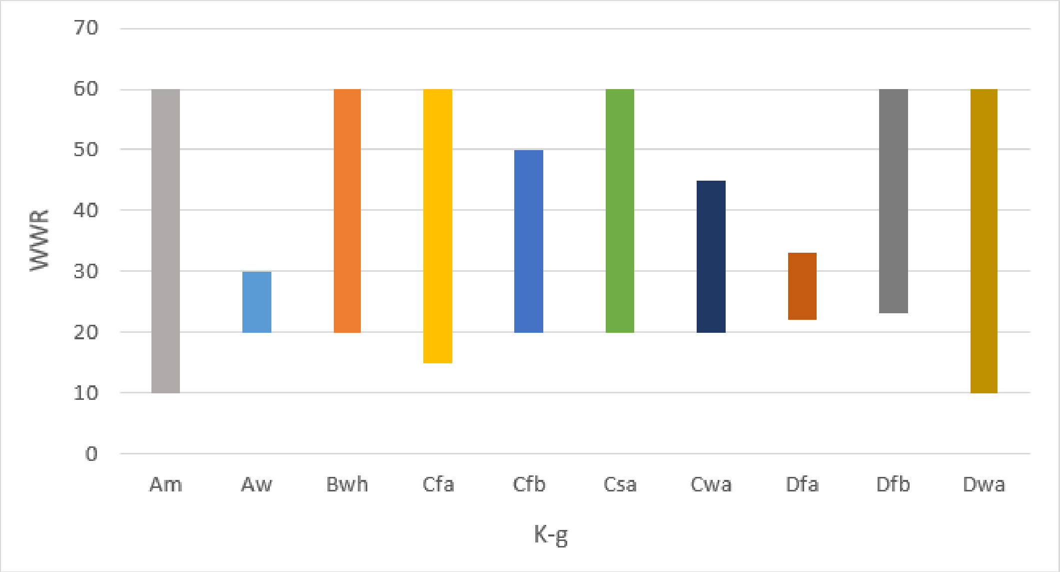


Figure 3. Suggested WWR for different (K-G)

4. Conclusion

In this review, the impact of WWR on lighting, cooling, and heating TEC in business, residential, school, and hospital buildings was examined in terms of TEC. Ten distinct (K-G) for 46 cities and 50 different buildings were evaluated. Due to the impact of numerous factors on WWR, observation revealed a wide range of WWR for climate zones, however, this research focused solely on the climate element. If a precise amount is considered for a building, all relevant factors, such as window position, window orientation, lighting intensity, building shape, glazing type, building height, window sunshade, window shape, and so on, must be accounted for in the simulation. The results indicate that total energy consumption has a logical relationship with TEC; for instance, at 0% WWR, TEC is high due to a lack of heat gain, and as WWR increases, TEC decreases until the optimum range, after which it increases again. it is a similar pattern for most climate zones for a regular window type.

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Comunicación alineada con los Objetivos de Desarrollo Sostenible