

Optimizing Energy Demand in Residential Buildings: Influence of WWR and Shading Across Five Distinct Climates

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Introduction:

- Buildings are responsible for 40% of global energy use and a major share of greenhouse gas emissions, making them a focus of global climate goals such as the Paris Agreement [1].
- Improving building envelopes—through insulation, window-to-wall ratio (WWR), and shading devices—is essential for reducing energy demand while maintaining comfort [2].
- The performance of these strategies is climate-dependent: optimal designs vary by orientation, region, and season.
- Thermal inertia and U-value significantly affect heating and cooling needs, especially in extreme climates [3].
- This study analyzes how WWR, shading, and insulation influence energy demand in five cities near 40° latitude, using dynamic simulations and statistical methods.

Methodology:

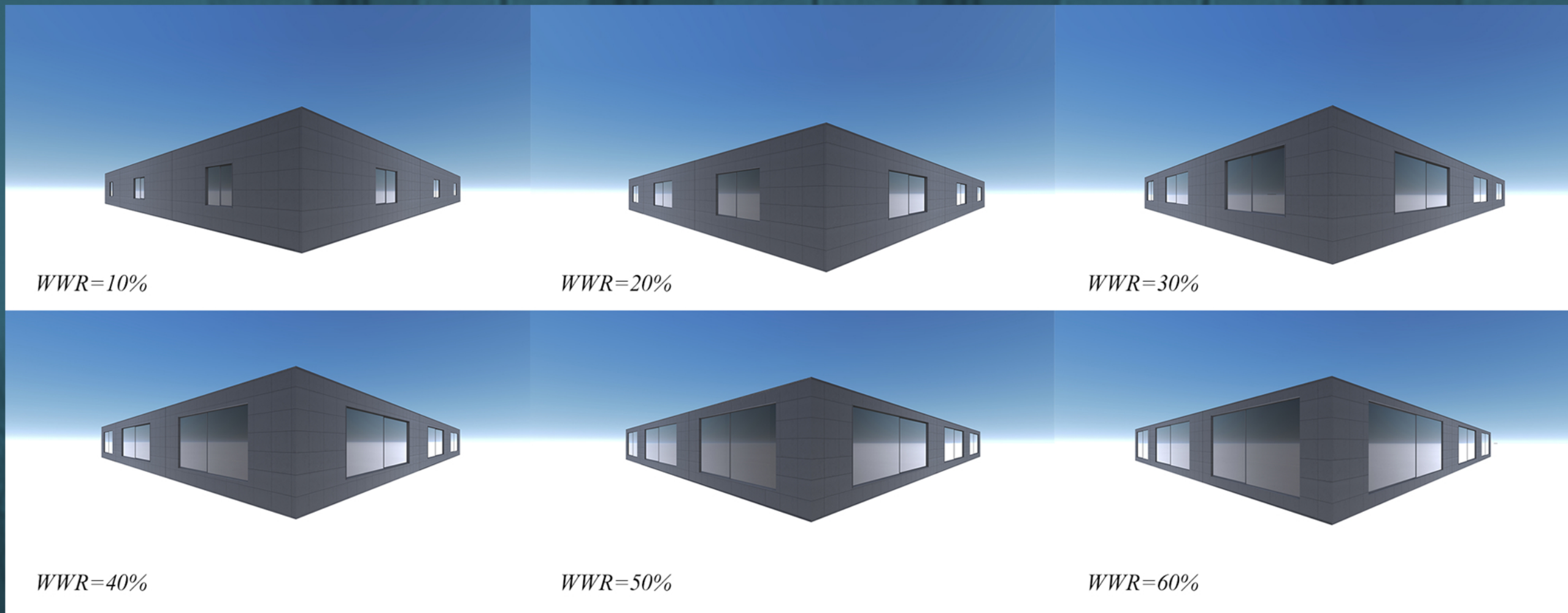
A residential building with a rectangular floor plan was modeled, comprising 8 apartments per floor, each representing a distinct thermal zone. While all units share the same floor area (96 m²), they differ in orientation and number of windowed facades (1 or 2)influencing exposure and solar gain.



The model was simulated using TRNSYS-18, integrated with SketchUp and TRN-Build, to evaluate annual heating, cooling, and total energy demand.

Key variables:

- Window-to-Wall Ratio (WWR): 10%–60%



- Wall insulation (U-values): 0.1 to 0.6 W/m²·K
- Shading scenarios: no shading, fixed (70 cm), and movable (triggered by temperature >24°C and radiation >200 W/m²)
- Simulations were conducted for five climate zones (Ankara, Beijing, New York, Rome, Wellington), all near 40° latitude, ensuring consistent solar exposure while covering diverse climatic conditions.
- Using real-world occupancy schedules and internal gains, a total of 4320 scenarios were run to explore the interaction of WWR, insulation, and shading on residential energy use.

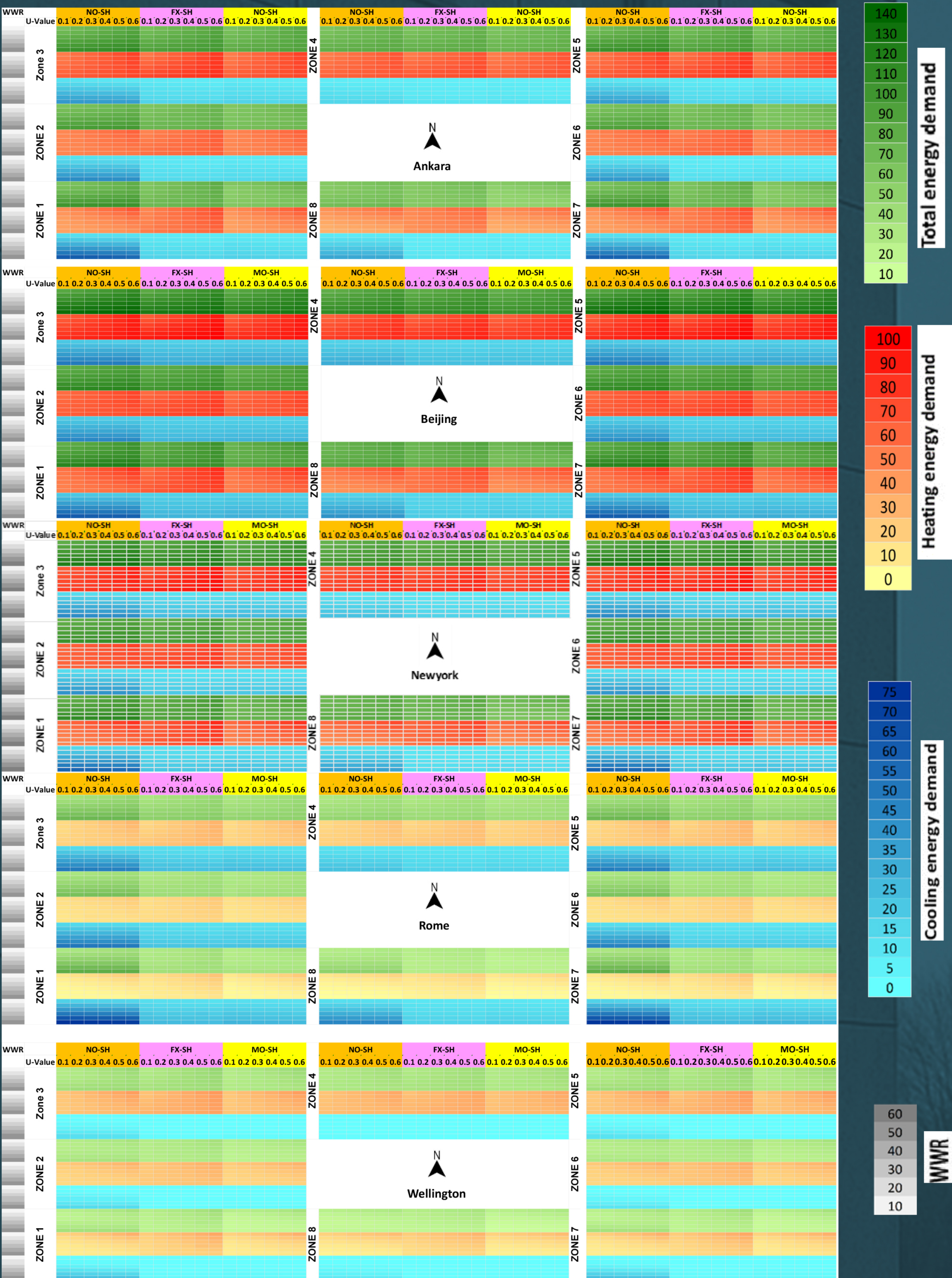
Input variables	Cases evaluated	Total
Location	Ankara; Beijing; New York; Rome; Wellington	5
WWR of each facade (%)	10; 20; 30; 40; 50; 60	6
U-value (W/m²K)	0.1; 0.2; 0.3; 0.4; 0.5; 0.6	6
Shading	No shading; fixed shading; movable shading	3
Thermal zones	8 apartments	8

Total cases 5 x 6 x 6 x 3 x 8 4320

Climate data sourced from Meteonorm; internal gains and schedules reflect realistic residential conditions.

Results:

- Total energy demand varied by city:
- Highest in Beijing and New York (80–115 kWh/m²·year)
- Moderate in Rome, lowest in Wellington
- Movable shading consistently reduced energy demand across most apartments and climates
- Apartments without shading showed noticeably higher energy use
- Fixed shading offered less consistent benefits
- Better insulation (lower U-values) led to reduced energy use in all cities except Rome
- Apartments 2 and 6 were especially sensitive to insulation improvements
- Window-to-Wall Ratio (WWR) affected both heating and cooling loads
- Higher WWR increased cooling demand
- Optimal WWR varied by apartment orientation and insulation level
- The best performance was achieved by combining movable shading, optimized WWR, and effective insulation



Conclusion:

- This study highlights the combined effect of shading, insulation (U-values), and window-to-wall ratio (WWR) on energy demand in residential buildings across five climates.
- Movable shading devices proved most effective in reducing energy use across most cities.
- Insulation had a strong impact, except in Rome, emphasizing the need for climate-specific strategies.
- WWR significantly influenced energy demand, especially in Apartments 2–6, depending on orientation.
- Overall, energy performance is highly dependent on context, reinforcing the importance of adaptive, zone-specific design for sustainable and efficient buildings.

References :

[1] UNEP. Emissions Gap Report (2019)
[2] Ahmed et al., J. Eng. Res. (2024)
[3] Božiček et al., Energies (2023)