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Article

Integrating Occupant Behavior into Window Design: A Dynamic Simulation Study for Enhancing Natural Ventilation in Residential Buildings

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Abstract

Predicted natural ventilation (NV) often diverges from actual performance in dwellings. This discrepancy arises in part because most design tools do not account for how occupants actually operate windows. This study aims to determine how window geometry and orientation should be adjusted when occupant behavior is considered. Survey data from 150 Melbourne residents were converted into two window-operation schedules: Same Behavior (SB), representing average patterns, and Probable Behavior (PB), capturing stochastic responses to comfort, privacy, and climate. Both schedules were embedded in EnergyPlus and applied to over 200 annual simulations across five window-design stories that varied orientations, placements, and window-to-wall ratios (WWRs). Each story was tested across two living room wall dimensions (7 m and 4.5 m) and evaluated for air-change rate per hour (ACH) and solar gains. PB increased annual ACH by 5–12% over SB, with the greatest uplift in north-facing cross-ventilated layouts on the wider wall. Integrating probabilistic occupant behavior into window design remarkably improves NV effectiveness, with peak summer ACH reaching 4.8, indicating high ventilation rates that support thermal comfort and improved IAQ without mechanical assistance. These results highlight the potential of occupant-responsive window configurations to reduce reliance on mechanical cooling and enhance indoor air quality (IAQ). This study contributes a replicable occupant-centered workflow and ready-to-apply design rules for Australian temperate climates, adapted to different climate zones. Future research will extend the method to different climates, housing types, and user profiles and will integrate smart-sensor feedback, adaptive glazing, and hybrid ventilation strategies through multi-objective optimization.

Keywords: indoor air quality (IAQ); natural ventilation (NV); occupants' behavior; occupants' perceptions; window design



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1. Introduction

Despite progressive building codes, sophisticated simulation tools [1], and increasingly ambitious energy-efficiency targets, a significant gap [2] often exists between predicted and actual measured building performance [3,4]. While inaccuracies due to construction practices and simplified modeling assumptions explain part of the discrepancy [5], recent field studies consistently highlight occupant behavior [6] as the significant yet overlooked factor influencing real-world outcomes [7–9]. In Australia, rating systems such as the

Nationwide House Energy Rating Scheme (NatHERS) acknowledge occupant-related factors, but their standard schedules rarely reflect the day-to-day variability of human decisions that directly shape indoor environmental quality (IEQ) and energy usage [10–12].

Among occupant-controlled actions, window operation has the most immediate and profound influence on natural ventilation (NV), indoor air quality (IAQ), and thermal comfort [13,14]. Unlike thermostat adjustments [15], shading control [16], or fan use, window interactions directly mediate airflow between indoor and outdoor environments [17–19]. Window-opening decisions are influenced by diverse personal, cultural, climatic, and socio-economic factors, such as energy cost sensitivity, housing type and density, and occupants' awareness [20–22]. The COVID-19 lockdowns amplified awareness of the health implications of inadequate ventilation and further highlighted the critical role windows play in maintaining safe and comfortable indoor environments [23–25].

While geometric characteristics, such as orientation, size, placement, operability [26,27], and window-to-wall ratio (WWR) [28,29], inherently determine ventilation potential, these features also significantly influence occupant behavior [30,31]. For instance, larger and well-oriented openings can physically facilitate higher air-change rates [32–34], yet they can unintentionally introduce excessive solar heat gains [35], a trade-off examined in studies on energy performance optimization in various climates [36–38]. Field-based studies on traditional architecture have also highlighted how natural wind patterns influence indoor thermal and humidity comfort, emphasizing the importance of passive ventilation design features in real-world performance [39]. Current standard simulation practices simplify these complex interactions by relying on static, rule-based schedules [40,41], ignoring the dynamic, adaptive nature of occupant responses, such as thermal comfort or privacy-driven behaviors, explored in previous studies [17,18]. Agent-based models, like those developed in the literature [42], attempt to capture more realism, but common simulation practices still struggle with behavioral nuances [43,44]. Consequently, many design recommendations mis-predict real-world NV performance [45,46], especially in mild temperate climates where window use is highly variable and adaptive comfort models are crucial [47,48].

Effectively closing this performance gap requires more integrated, behavior-aware modeling workflows that combine empirical occupant observations, such as those gathered from surveys and post-occupancy evaluations (POEs) [49–51], which reveal occupant preferences and actions [12,17], with computational tools like Computational Fluid Dynamics (CFD) [31,52] and energy models that assess physical performance [53,54]. Furthermore, emerging data-driven techniques, such as Artificial Intelligence (AI) in building energy management [55], machine learning models predicting occupancy and window use [56,57], and multi-criteria decision methods (MCDMs) for evaluating complex systems [58,59], offer powerful ways to analyze these interactions. Such hybrid approaches can reveal how occupants respond to thermal and visual cues [60,61] and how window geometry can nudge them towards healthier and more energy-efficient patterns [62,63]. However, existing studies have not combined empirical behavior models with systematic window-design exploration in a replicable simulation-based framework. Although these sophisticated methods exist, practical integration into current design practices remains limited. This highlights the need for straightforward yet realistic simulation approaches that blend detailed occupant insights with proven simulation tools to provide clear, actionable guidance on how window designs influence real occupant behaviors and NV performance.

Addressing this critical gap, the present study introduces a novel user-centric simulation framework, explicitly coupling probabilistic occupant behavior models derived from empirical surveys with systematic window-design exploration. Adapted to Australian temperate climates, this approach leverages two distinct window-operation schedules, Same Behavior (SB), reflecting typical use patterns, and Probable Behavior (PB), capturing

more realistic occupant variability, and evaluates them within the EnergyPlus simulation environment. Through more than 200 annual simulations, this research aims to answer two main questions: (i) Which specific window-design attributes most enhance NV when real occupant actions are considered? and (ii) How much does incorporating realistic occupant behavior (PB) improve ventilation outcomes compared to standard simulation assumptions (SB)? By quantifying these links, this study offers new, ready-to-apply design rules tailored for behavior-integrated window design, helping architects and engineers narrow the ventilation performance gap in residential buildings [64,65]. The following sections detail the survey methodology, and simulation framework (Section 2) and results and practical implications (Section 3), discuss limitations and directions for future research (Section 4), and conclude by summarizing key insights and recommendations (Section 5).

2. Methodology

This study deploys a behavior-integrated simulation framework to explore how window-design features and real-world occupants collectively affect NV performance in residential buildings located in the temperate climate of Melbourne, Australia. Two distinct occupant–window operation schedules were developed based on survey data from 150 Melbourne households [20]:

- Same Behavior (SB): a deterministic schedule representing average occupant behavior.
- Probable Behavior (PB): a stochastic (probabilistic) schedule capturing variations due to factors like comfort, privacy, and climate conditions. PB was derived by assigning time-of-day-dependent probabilities to window actions based on survey responses; no thermal comfort models (e.g., Fanger) were used. Further details are available in Appendix A.

Both schedules were integrated into EnergyPlus (version 9.6.0) simulations to quantify their impacts on air-change rate per hour (ACH), indoor temperatures, and solar gains. Five distinct window-design scenarios, named stories, including different orientations, placements, and WWR = 0.25–0.60, were evaluated across two typical living room wall sizes: a larger wall (7 m) and a smaller wall (4.5 m). A total of 200 annual simulations (five design scenarios $\times$ two wall sizes $\times$ multiple configurations $\times$ two behavior schedules) form the basis for the resulting design guidelines. Figure 1 summarizes the overall workflow, while detailed dimensions and behavior schedules are provided in Appendix A.

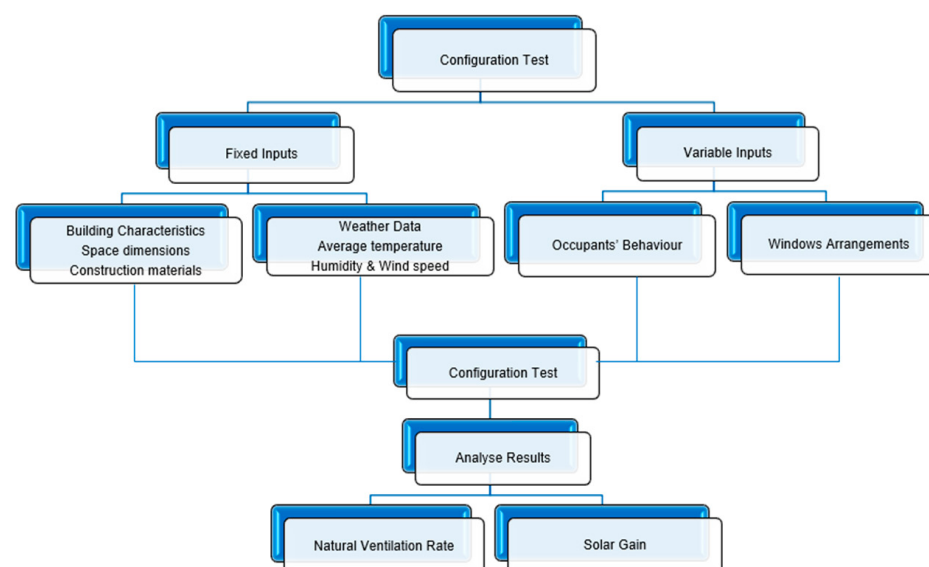


Figure 1. Methodological flowchart.

2.1. Simulation Model Setup

The simulation approach uses clearly defined types of inputs:

- Fixed inputs, such as building characteristics, materials, spatial dimensions, and climatic data (temperature, humidity, wind speed), remain constant across all simulations to ensure comparability.
- Variable inputs, window configurations, and occupant behavior schedules change systematically to evaluate their individual and combined impacts on NV performance.

The methodological workflow, including input categorization, simulation configuration, and result analysis, is illustrated in Figure 1.

2.1.1. Fixed Inputs

The fixed inputs were defined to reflect a typical residential living room in Melbourne, Australia, consistent with local construction practices [66] and aligned with the National Construction Code (NCC) [67]. The model includes two wall dimensions (7 m and 4.5 m) and a standard ceiling height of 2.4 m, representing approximately 13.3% of an average 235.8 m² detached home, based on typical Australian housing data and industry practices [66,68]. This simulated single-zone building serves as a generic representation of common residential spaces rather than a specific physical case study, enabling generalizable insights. The construction follows a common brick veneer system with an air cavity, reflective sarking, and internal plasterboard, selected for its durability and thermal performance in temperate climates [10]. Windows are specified as double-glazed low-emissivity (low-E) glass with thermally broken aluminum frames [69], offering a U-value of 2.8–3.2 W/m²·K and a solar heat gain coefficient (SHGC) of 0.40–0.50, suitable for NCC Climate Zone 6 [10]. Weather data were sourced from the Bureau of Meteorology (BOM), providing hourly records of temperature, humidity, wind speed, and solar radiation for Melbourne. Specifically, the simulations utilized a standard EPW (EnergyPlus Weather) file derived from BOM data, representing a Typical Meteorological Year (TMY) for the Melbourne region. These detailed hourly climate data are critical for accurately simulating the dynamic interactions between the building and its environment, particularly for assessing natural-ventilation performance under varying external conditions. These fixed parameters established a realistic and standardized simulation baseline for assessing the influence of variable window configurations and occupant behaviors on natural-ventilation performance. Hourly meteorological files from the Bureau of Meteorology supply temperature, humidity, wind speed and direction, and solar radiation for a Typical Meteorological Year in Melbourne [70]. Locking these boundary conditions, together with geometry, construction, and glazing, creates a common baseline against which 200 alternative window layouts and two occupant-schedule sets (SB and PB) can be compared. The literature highlights that these attributes—room geometry, wall mass, glazing performance [69], and boundary climate—govern both the physical potential for airflow and the energy penalty of unwanted heat gains [14,71]. By locking them as fixed inputs (Table 1), this study removes confounding factors and isolates the effects of the variable inputs explored later (window layout and occupant schedules), thereby creating a rigorous baseline for assessing behavior-sensitive natural-ventilation performance.

Table 1. Fixed input parameters used across all simulations.

Parameter Type	Fixed Inputs	Description
Building dimensions	Typical living room, ceiling height 2.4 m	Living room with wider and smaller wall dimensions, which match standard dimensions for Melbourne homes
Wall construction	Brick veneer, air cavity, reflective sarking, plasterboard	Standard local wall construction
Window specifications	Double-glazed low-E glass, thermally broken aluminum frames	U-value: 2.8–3.2 W/m ² ·K; SHGC: 0.40–0.50
Weather data	Hourly temperature, humidity, wind speed, and solar radiation	Melbourne climate, Typical Meteorological Year

2.1.2. Variable Inputs

These inputs included window configurations and occupant behavior schedules, adjusted across different design stories to capture dynamic interactions affecting NV. Window configurations were organized into five design stories, each focusing on a specific orientation to reflect occupant preferences identified in a prior post-occupancy evaluation (POE) conducted through a qualitative questionnaire targeting 150 residents aged 18 and older in Melbourne, Australia, as detailed in earlier work. The survey covered demographics, building features, occupant behaviors, ventilation options, and comfort perceptions. These primarily consisted of detached and semi-detached dwellings located across Melbourne suburbs. The average residence size was 196.7 m², with living rooms averaging 33.5 m². In terms of orientation, 79% of the buildings had windows on the north wall, 67% on the east, 58% on the west, and 55% on the south wall, providing useful context for the orientation-focused design stories. An analysis using Pearson's correlation identified factors influencing window operation, such as preferences for certain orientations, motivations for opening windows, and barriers like privacy and heat, particularly at night, with details available in prior work [20].

The occupant behavior schedules (SB and PB) were developed from a survey of 150 Melbourne households, as detailed in our previous study (Pourtangestani et al., 2024, ref. [20]). The survey focused on residents in detached and semi-detached homes (average size 196.7 m²) and collected information on demographics, window-operation habits, and factors influencing these behaviors, such as comfort, privacy, and climate. Participants reported how often and when they opened windows, along with their reasons.

From this data, the SB schedule was created by averaging the window-opening frequencies across all respondents, resulting in a consistent daily pattern. The PB schedule captures variability by assigning time-of-day probabilities based on common responses, for example, a 70% chance of opening a north-facing window at 8 AM. This probabilistic approach reflects real occupant variability without relying on thermal comfort models, since the survey directly captures local adaptive behaviors.

Further details on the survey methods, questionnaire design, and statistical analysis (including Pearson's correlation) can be found in ref. [20] and Appendix A, providing a solid foundation for the behavior models used in EnergyPlus simulations.

Five distinct window-design stories (summarized in Table 2) were developed to reflect occupant preferences for orientation, ventilation needs, and daylight access. Each story was tested using two spatial scenarios: Scenario A (wider wall: 7 m × 2.6 m) and Scenario B (smaller wall: 4.5 m × 2.6 m), to assess how room geometry influences geometry on occupant–window interactions and resulting ventilation outcomes. While tailored to Melbourne's temperate climate, this framework is readily adaptable to other

regions by modifying the weather file and adjusting fixed parameters such as materials or occupancy assumptions.

Table 2. Summary of window-design stories and behavior model rationales.

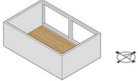
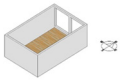
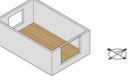
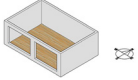
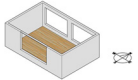
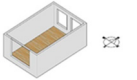
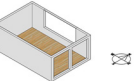
Design Story	Orientation	Configuration	WWR	Configuration Rationale
Story 1	North	Dual window	45%	– Directly responds to the strongest orientation preferences. – Side-by-side configurations showed high occupant interaction, particularly for achieving fresh air. – Size 45% WWR represents the occupant’s desire for ample daylight/view.
Story 2	East–west	Single window	E 40% W 30%	– Large east-facing window extending towards the ceiling for optimal light; takes advantage of morning light and passive heating. – The west window helps manage afternoon heat gain. – Provides cross-ventilation.
Story 3	South	Dual window	30% each	– Investigate occupant interaction with an orientation known for consistent, diffuse daylight and minimal direct solar heat gain/glare. – Side-by-side configuration, which has high occupant interaction for ventilation and general use. – Moderate 60% WWR, provides substantial natural light, aligning with occupant preference for light/view.
Story 4	North and south	Dual north, single south	S 40% N 25% each	– Preferred north orientation for potential winter solar gain and ventilation. – The large, ceiling-height south-facing dimension enhances daylight penetration. – Design maximizes cross-ventilation potential by utilizing both north and south orientations.
Story 5	North and east	Single north, dual east	N 40% E 25% each	– Combination of preferred orientations. – The north window incorporates the strongly preferred north orientation for ventilation and stable daylight. – East windows leverage the benefits of the east morning light.

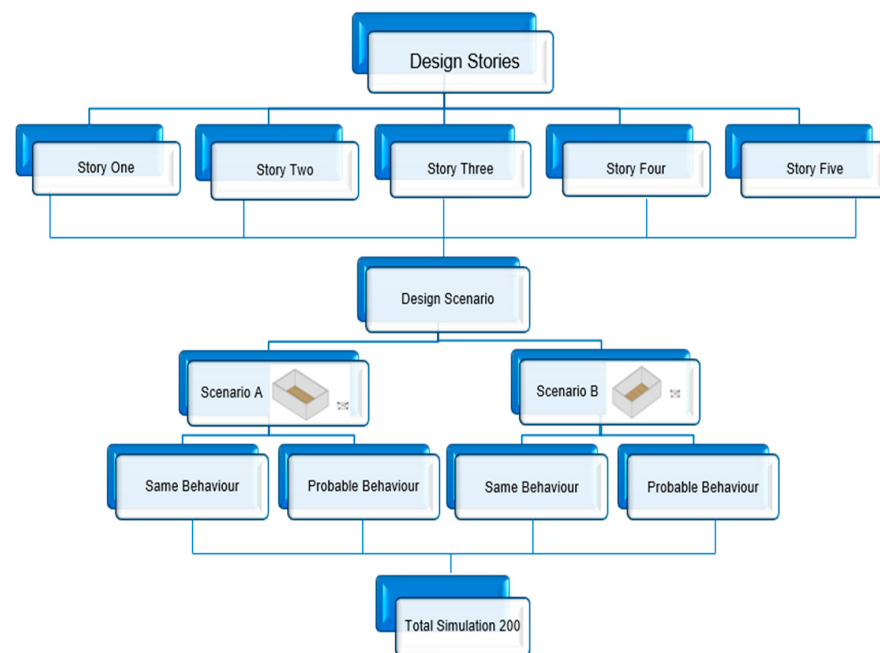
These models included adaptive strategies where occupant behavior varied by wall size and window orientation, for example, residents opened north-facing windows more frequently on larger walls to maximize airflow but were more conservative with south-facing windows to minimize heat gains during midday hours. Table 3 summarizes these patterns across all five design stories, showing how behavior changes with orientation and wall size. This table highlights the importance of integrating such variability into ventilation design.

This structured and systematic approach, outlined in Figure 2, produced 200 simulation variations, enabling comprehensive examination of how occupant behaviors and window configurations jointly influence NV performance.

Simulations were conducted in EnergyPlus for a single-zone living room (7 m × 4.5 m × 2.4 m) with brick veneer walls ($U = 0.5 \text{ W/m}^2\cdot\text{K}$), tiled roof ($U = 0.3 \text{ W/m}^2\cdot\text{K}$), and a concrete floor (thermal mass = $120 \text{ kJ/m}^2\cdot\text{K}$). Windows ($U = 2.8\text{--}3.2 \text{ W/m}^2\cdot\text{K}$, SHGC = 0.40–0.50) were modeled with full radiative and convective heat transfer. Simulations ran from 6:00 AM to 10:00 PM; windows were closed overnight (10:00 PM–6:00 AM) for safety and during June–August for winter heat retention. Opening percentages reflected occupant behavior via SB and PB schedules (Appendix A). The Airflow Network module calculated airflow rates (2–30 ACH) based on window design (WWR = 0.25–0.60), wind pressure, and Melbourne TMY data (temperatures 5–35 °C, wind 2–5 m/s, RH 50–70%). Solar radiation was modeled using the Perez sky model, with peak irradiance values up to $\sim 800 \text{ W/m}^2$ based on TMY data for Melbourne. A 10 min timestep and SIMPLE solver ensured stability across 200 simulations covering five design stories, two wall sizes, and two behavior models.

Table 3. Behavior model rationale by design story and room scenario.

Design Story	Orientation	Scenario A	Scenario B	SB Rationale	PB Rationale
Story 1	North			Regular morning and evening openings.	On wider walls, it increases morning openings for wind; on smaller walls, less frequent due to limited airflow.
Story 2	East and west			Morning openings (east), evening openings (west).	On wider walls, boosts east morning openings for light; on smaller walls, reduces west midday openings for heat control.
Story 3	South			Less frequent openings due to limited wind exposure.	On wider walls, reduce midday openings to manage heat; on smaller walls, further limited due to weaker ventilation potential.
Story 4	North and south			Frequent openings for cross-ventilation, especially mornings.	On wider walls, enhances morning cross-ventilation; on smaller walls, reduces south midday openings for heat control.
Story 5	North–east			East morning openings for light, north for steady ventilation.	On wider walls, boosts east morning openings; on smaller walls, adjusts north for consistent airflow throughout the day.

**Figure 2.** Design stories and design scenarios.

2.2. Results Analysis Method

Simulation outputs from EnergyPlus were analyzed using two primary performance indicators: natural-ventilation rates (ACH) and solar gains (kWh). These metrics allowed assessment of the effectiveness of different window configurations and occupant behaviors in enhancing airflow and managing heat gains. Results were comparatively evaluated across the five design stories and two wall-size scenarios under both SB and PB behavior models. Additional factors, such as seasonal climate variations and detailed occupant interactions, were considered, enabling a systematic and realistic evaluation of how window configurations and occupant behaviors interact to influence NV performance in residential buildings.

3. Results and Discussion

This section presents the detailed results from simulations evaluating five different window-design stories, aimed at optimizing NV by accounting for realistic occupant behaviors in Melbourne’s temperate climate. Each design story considers two distinct room sizes: Scenario A (7 m × 2.6 m wall) and Scenario B (4.5 m × 2.6 m wall), to assess how window geometry and occupant interaction patterns affect ventilation and solar heat gains. Results focus primarily on identifying window features that encourage frequent occupant engagement rather than simply increasing window size or quantity. Solar gains, determined by window dimensions, orientations, and glass properties, are unaffected by occupant behavior (SB or PB), as window operations in this study drive ventilation rates (ACH) rather than solar heat transfer. Future work will explore occupant behavior for solar gain control, such as adaptive shading or window adjustments, which was not considered in the current research.

3.1. Design Story 1: North-Facing Windows (WWR 45%)

The configuration features two side-by-side north-facing windows, tested under two scenarios: Scenario A and Scenario B as detailed in Tables 4 and 5. The results are as detailed in Sections 3.1.1 and 3.2.2.

Table 4. Window configurations: Design Story 1, Scenario A.

Config	Window 1 (H × W, m)	Window 2 (H × W, m)	Ventilation/Lighting Impact
1	2.4 × 1.70	2.4 × 1.70	Maximizes daylight penetration; high ACH due to tall windows.
2	2.2 × 1.85	2.4 × 1.85	Proportional windows enhance light uniformity and cross-ventilation.
3	2.0 × 2.05	2.0 × 2.05	Balanced dimensions for airflow and daylight; moderate ACH.
4	1.8 × 2.30	1.8 × 2.30	Wider windows spread horizontal daylight; good ventilation.
5	1.5 × 2.70	1.5 × 2.70	Shorter windows reduce glare; lower ACH due to height.
6	1.6 × 3.4	1.6 × 1.7	Wider Window 1 boosts ventilation; Window 2 aids flexibility.
7	1.6 × 2.05	1.6 × 3.05	Wider Window 2 enhances light spread; balanced airflow.

Table 5. Window configurations: Design Story 1, Scenario B.

Config	Window 1 (H × W, m)	Window 2 (H × W, m)	Ventilation/Lighting Impact
9	2.4 × 1.10	2.4 × 1.10	Tall windows maximize vertical daylight; high ACH.
10	2.0 × 1.3	2.0 × 1.3	Balanced dimensions optimize ventilation and lighting.
11	1.8 × 1.45	1.8 × 1.45	Wider windows emphasize horizontal daylight spread.
12	1.5 × 1.75	1.5 × 1.75	Shorter windows reduce glare; focus on horizontal daylight.
13	2.2 × 1.20	2.2 × 1.20	Proportional windows ensure symmetrical lighting; good ACH.

Table 5. *Cont.*

Config	Window 1 (H × W, m)	Window 2 (H × W, m)	Ventilation/Lighting Impact
14	1.6 × 1.1	1.6 × 2.2	Wider Window 2 boosts light and ventilation; Window 1 complements.
15	1.6 × 1.3	1.6 × 2.0	Wider Window 2 enhances horizontal daylight; steady airflow.

3.1.1. Scenario A: 7.0 m × 2.6 m

Table 4 presents the window configurations (1–7) for Design Story 1, Scenario A, featuring north-facing windows on a 7.0 m × 2.6 m wall.

North-facing dual-window configurations demonstrated strong NV performance, particularly when window height was maximized. As shown in Table 6, the tallest configuration (Config. 1) achieved a peak rate of 4.67 ACH in March and an annual average of 3.47 ACH, outperforming the shortest configuration by up to 17%. The PB model, which reflects adaptive user patterns such as morning and evening ventilation, further improved monthly ACH by 8.7% to 12.7% over the SB model, particularly during transitional months like March and May (Figure 3). Across all configurations, PB increased monthly ventilation by approximately 10% on average, with peak gains reaching nearly 13%. These results underscore the value of aligning window design with actual occupant routines rather than relying on static operation assumptions. The findings confirm that occupant interaction plays a pivotal role in achieving optimal NV, even when geometric configurations are already favorable.

Table 6. Natural-ventilation performance of north-facing windows (Scenario A, SB Model).

Configuration	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH)
1	4.67 (March)	1.95 (May)	3.47
2	4.52 (March)	1.89 (May)	3.36
3	4.40 (March)	1.89 (May)	3.31
4	4.31 (March)	1.86 (May)	3.23
5	3.95 (March)	1.72 (May)	2.97
6	4.06 (March)	1.78 (May)	3.06
7	4.06 (March)	1.77 (May)	3.06

However, greater window height and width also resulted in increased solar gains, advantageous in cooler months but potentially problematic during summer. For instance, solar heat gains were substantial in spring (exceeding 400 kWh in March and May), indicating that without shading, large north windows could cause overheating. Although solar exposure was not directly modeled as an input to occupant behavior, the correlation between elevated internal heat and increased window operation suggests that users instinctively respond to thermal cues. To optimize year-round performance, it is recommended that shading devices or dynamic glazing be integrated into designs featuring large north-facing windows. This approach balances passive solar benefits with the need to avoid overheating during warmer periods.

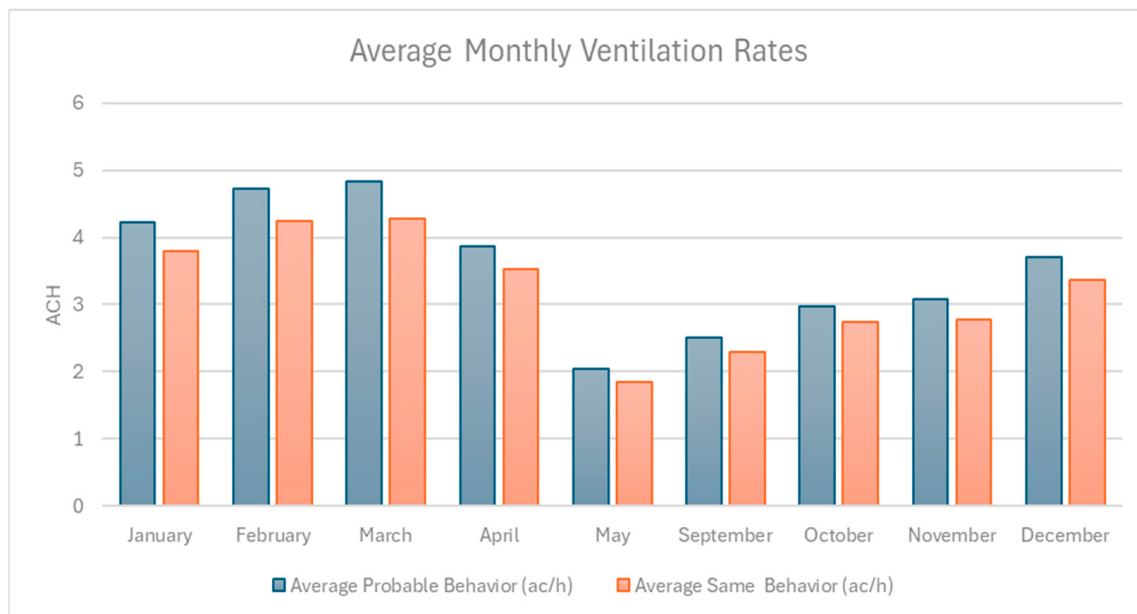


Figure 3. Story 1, Scenario A, average monthly ventilation rates, SB vs. PB.

Solar gain in Scenario A was also substantial, with peak monthly values exceeding 400 kWh, particularly in configurations with taller or wider glazing (Table 7). Although solar gain was not explicitly modeled as a behavioral input, it likely influenced window use, especially during cooler months when passive heating is desirable. Notably, in warmer months such as February, higher solar exposure coincided with increased ventilation rates, indicating that heat buildup may have prompted occupants to open windows for thermal comfort. These observations highlight the dual function of north-facing windows in supporting both passive heating and ventilation. To prevent overheating in summer while preserving these benefits, the use of external shading or low-SHGC glazing is strongly recommended.

Table 7. Ventilation and solar gain, Design Story 1, Scenario B (SB and PB).

Month	Highest NV Probable (ACH) (Config.)	Lowest NV Probable (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	4.12 (1)	3.49 (5)	3.80	4.23	+11.2%	228.15	238.93 (4)	219.66 (1)
Feb	4.63 (1)	3.90 (5)	4.24	4.72	+11.3%	235.29	275.27 (4)	219.66 (1)
Mar	4.67 (1)	3.95 (5)	4.28	4.83	+12.7%	294.62	408.14 (4)	219.66 (1)
Apr	3.80 (1)	3.27 (5)	3.52	3.86	+9.6%	291.09	404.11 (4)	219.66 (1)
May	1.95 (1)	1.72 (5)	1.84	2.05	+11.3%	298.98	436.76 (4)	219.66 (1)
Sep	2.41 (1)	2.16 (5)	2.29	2.51	+9.5%	237.18	404.32 (4)	219.66 (1)
Oct	2.92 (1)	2.55 (5)	2.74	2.97	+8.7%	246.09	336.10 (4)	219.66 (1)
Nov	3.00 (1)	2.60 (5)	2.78	3.08	+10.8%	228.13	242.85 (4)	219.66 (1)
Dec	3.67 (1)	3.13 (5)	3.37	3.70	+9.6%	223.04	223.81 (4)	219.52 (2)

3.1.2. Scenario B: 4.5 m × 2.6 m

Scenario B applied the same north-facing orientation and 45% WWR to a shorter 4.5 m wall, with proportionally scaled window dimensions. Table 5 presents the window configurations.

NV performance followed a similar seasonal pattern to Scenario A, peaking in late summer, particularly February, when prevailing winds were more favorable, and declining sharply into late autumn. As shown in Table 8, Configuration 9 achieved the highest peak

ventilation rate of 2.86 ACH in February and the highest average of 2.09 ACH across the year, while Configuration 12 recorded the lowest performance with a peak of 2.44 ACH and an average of 1.84 ACH. These results confirm that taller window configurations continued to outperform shorter ones even on smaller wall areas, although the overall ventilation potential was lower than in Scenario A due to reduced façade dimensions. Complete window closure in the coldest winter months further constrained NV performance, reinforcing the need to balance spatial constraints with design elements that support airflow under varying seasonal conditions.

Table 8. Natural-ventilation performance of north-facing windows (Scenario B, SB Model).

Configuration	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH)
9	2.86 (February)	1.00 (May)	2.09
10	2.67 (February)	0.96 (May)	1.97
11	2.58 (February)	0.95 (May)	1.92
12	2.44 (February)	0.92 (May)	1.84
13	2.79 (February)	1.00 (May)	2.06
14	2.52 (February)	0.95 (May)	1.89
15	2.52 (February)	0.94 (May)	1.89

Figure 4 further illustrates the average monthly ventilation rates for Scenario B under both SB and PB models. The figure highlights a consistent uplift in ventilation performance when occupant variability is considered. Across all months, PB yields higher ACH values than SB, with the most pronounced gains observed during transitional months like May, September, and October, ranging from approximately 8% to 12%. In summer months (January–March), the difference between PB and SB narrows, suggesting that even baseline patterns align reasonably well with environmental drivers. However, during shoulder seasons, occupants under PB adapt window use more responsively to temperature and airflow cues, enhancing NV effectiveness. These results reinforce the importance of integrating adaptive behavior into window-design strategies, particularly in spatially constrained layouts like Scenario B.

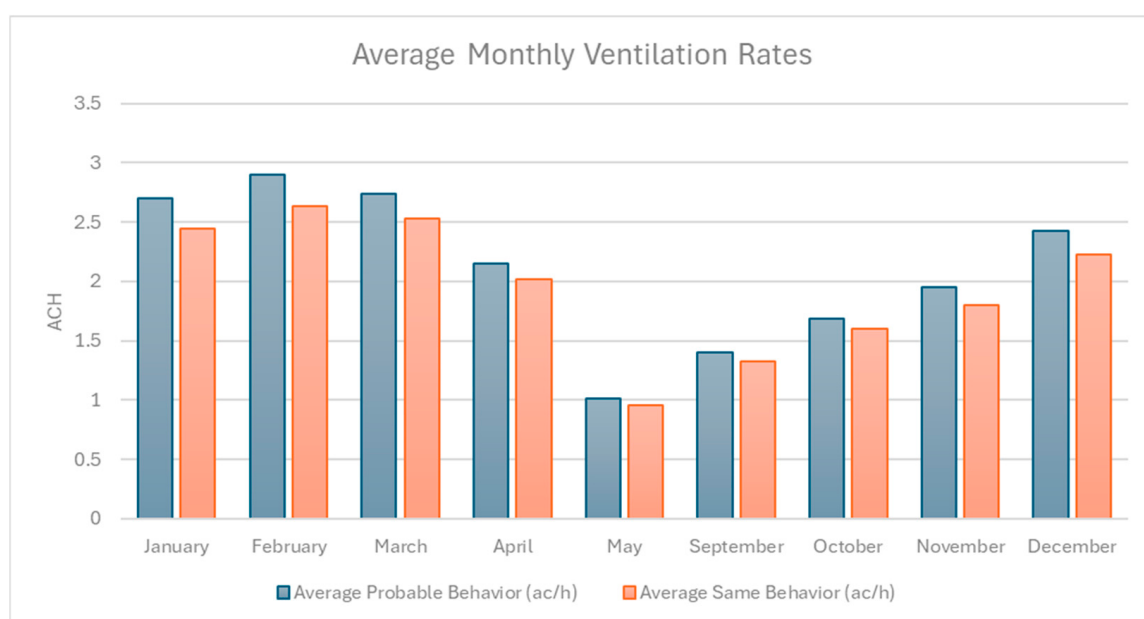


Figure 4. Natural-ventilation rates across stories, SB (Scenario B).

Table 9 compares the monthly performance of NV and solar gain for Design Story 1, Scenario B, under SB and PB models. Configuration 9 consistently achieved the highest NV rates, while Configuration 12 remained the lowest performer. The PB model led to steady gains in ventilation across all months, with average increases ranging from 5.1% in May to 10.6% in January, particularly notable during warmer and transitional months like February (+10.3%) and December (+9.0%). Although solar gains were moderate due to smaller glazing areas, they peaked at nearly 272 kWh in May (Config. 15) and aligned with higher ventilation activity during warmer months, suggesting that internal heat buildup prompted increased window operation. These results highlight the importance of accounting for both adaptive occupant behavior and passive solar exposure, especially in compact wall designs where spatial constraints limit airflow potential.

Table 9. Ventilation and solar gain under SB and PB models (Scenario B).

Month	Highest NV Probable (ACH) (Config.)	Lowest NV Probable (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	2.65 (9)	2.28 (12)	2.44	2.70	+10.6%	148.05	149.23 (15)	146.07 (10)
Feb	2.86 (9)	2.44 (12)	2.63	2.90	+10.3%	171.27	171.63 (15)	168.05 (10)
Mar	2.75 (9)	2.37 (12)	2.53	2.74	+8.1%	251.70	254.26 (15)	248.99 (10)
Apr	2.14 (9)	1.91 (12)	2.02	2.15	+6.4%	249.46	251.69 (15)	246.49 (10)
May	1.00 (9)	0.92 (12)	0.96	1.01	+5.1%	269.41	271.97 (15)	266.36 (10)
Sep	1.41 (9)	1.29 (12)	1.33	1.40	+5.2%	249.51	251.86 (15)	246.65 (10)
Oct	1.70 (9)	1.51 (12)	1.60	1.69	+5.5%	207.85	209.49 (15)	205.12 (10)
Nov	1.92 (9)	1.70 (12)	1.80	1.95	+8.6%	150.15	151.62 (15)	148.42 (10)
Dec	2.40 (9)	2.10 (12)	2.23	2.43	+9.0%	148.62	149.94 (15)	136.96 (10)

Solar gain in Scenario B, while lower than those in Scenario A due to reduced total glazing area, remained significant, ranging from 148 kWh in January to a peak of nearly 272 kWh in May. These values, though modest, are sufficient to influence indoor thermal conditions during transitional seasons and likely contributed to increased ventilation activity under the PB model. As shown in Table 9, months with higher solar gain, such as February and March, coincided with elevated NV rates, reinforcing the hypothesis that internal heat accumulation encourages occupants to open windows for cooling. Configuration 15 consistently exhibited the highest solar gains across all months, reflecting the role of window dimensions in modulating passive heat entry. This finding highlights the dual influence of geometry and adaptive behavior in shaping NV outcomes. To enhance thermal comfort without compromising airflow, especially during warmer periods, the integration of external shading or advanced glazing strategies should be considered in future adaptive design solutions.

3.1.3. Discussion: Design Implications and Behavioral Insights

Larger north-facing windows clearly improved ventilation, but effective passive design also required occupant-responsive use and shading to avoid overheating. Scenario A suits cooler contexts needing passive heating, while Scenario B may be better for warmer climates, offering effective NV without excessive solar heat gain.

3.2. Design Story 2: East and West Configuration

Design Story 2 examines a system with a large east-facing window, 40% WWR, and a smaller west-facing window, 30% WWR, on opposing walls. This design story aims to promote NV and support occupant comfort throughout the day. A large east-facing window, extending to the ceiling, captures early daylight and warmth, while a smaller west-facing window supports cross-ventilation in the afternoon. The configuration is

tailored to Melbourne’s climate, where mornings are often cool and breezy, and afternoons can become warm and still. Occupant behavior in this scenario involves using the east window actively in the morning and gradually shifting to the west-facing opening later in the day, with both windows opened fully in the evening to maximize cross-ventilation. Nine configurations detailed in Tables 10 and 11 were tested for both Scenarios A and B, each varying in window dimensions to assess their impact on ventilation performance and occupant interaction.

Table 10. Window configurations: Design Story 2, Scenario A.

Config.	East Window (H × W, m)	West Window (H × W, m)	Ventilation/Lighting Impact
1	2.4 × 3.0	2.4 × 2.3	Tall windows maximize daylight/ventilation; narrow west manages heat.
2	2.2 × 3.3	2.2 × 2.5	Balanced windows optimize light/ventilation; glare control.
3	2.0 × 3.65	2.0 × 2.75	Wider east enhances morning light; moderate ACH.
4	1.8 × 4.05	1.8 × 3.05	Wide windows emphasize horizontal airflow. Glare management needed.
5	1.6 × 4.55	1.6 × 3.4	Wide windows maximize horizontal connection; risk of overheating.
6	2.4 × 3.0	1.6 × 3.2	Tall east maximizes morning light; low west limits PM heat.
7	2.2 × 3.3	1.8 × 3.0	Tall east enhances AM light; lower west balances heat.
8	1.8 × 4.0	2.2 × 2.45	Low east manages glare; taller west aids PM ventilation.
9	1.6 × 4.5	2.4 × 2.25	Low east maximizes view; tall west needs PM control.

Table 11. Window configurations: Design Story 2, Scenario B.

Config.	East Window (H × W, m)	West Window (H × W, m)	Ventilation/Lighting Impact
1	2.4 × 1.95	1.6 × 2.15	Tall east optimizes AM light; low west aids PM heat control.
2	2.2 × 2.1	1.8 × 1.95	Balanced heights ensure versatile ventilation and light.
3	1.8 × 2.6	2.2 × 1.6	Low east manages glare; tall west provides focused airflow.
4	1.6 × 2.9	2.4 × 1.45	Low east maximizes view; tall west offers good PM control.
5	2.4 × 1.9	2.4 × 1.45	Tall, narrow windows optimize vertical light; PM control needed.
6	2.2 × 2.1	2.2 × 1.55	Mid-height windows balance light/airflow; west limits heat.
7	2.0 × 2.3	2.0 × 1.7	Wider east enhances AM light; narrower west balances heat.
8	1.8 × 2.55	1.8 × 1.8	Low windows emphasize horizontal connection; consistent airflow.
9	1.6 × 2.9	1.6 × 2.1	Low windows maximize view/airflow; east enhances AM light.

3.2.1. Scenario A: 7 m × 2.6 m East and West Walls

The NV rates across configurations show seasonal fluctuations, peaking in summer due to stronger winds, warmer temperatures, and increased occupant tendency to open windows, and dipping in late autumn as winds weaken and temperatures cool. Scenario A consistently exhibited strong ventilation performance, with peak average NV occurring in January and the lowest rates in May, when outdoor conditions were less favorable. This seasonal dip also aligns with occupant reluctance to open windows during colder periods. A summary of peak, lowest, and average ACH for each configuration in Scenario A is provided in Table 12.

Configurations with wider east-facing windows and balanced west-facing openings consistently outperformed others, highlighting the critical role of window sizing and placement in promoting cross-ventilation. Configuration 5 recorded the highest NV rates, while Configuration 6 had the lowest. Wider east-facing windows proved effective in capturing morning inflow, while balanced west openings enhanced afternoon exhaust.

Configurations with smaller west-facing windows performed less effectively, particularly in cooler months.

Table 12. Natural ventilation performance of east–west window designs (Scenario A).

Configuration	Peak (ACH)	Lowest (ACH)	Average (ACH)
1	26.83 (January)	1.81 (May)	13.83
2	26.82 (January)	1.79 (May)	13.79
3	26.74 (January)	1.79 (May)	13.77
4	26.58 (January)	1.73 (May)	13.54
5	27.22 (January)	1.80 (May)	14.02
6	25.40 (January)	1.65 (May)	12.70
7	26.44 (January)	1.74 (May)	13.45
8	26.31 (January)	1.74 (May)	13.38
9	26.46 (January)	1.77 (May)	13.43

Probable occupant behavior modeled to reflect daily routines and adaptive use of the windows resulted in consistent, albeit modest, improvements in NV across all months, as illustrated in Figure 5.

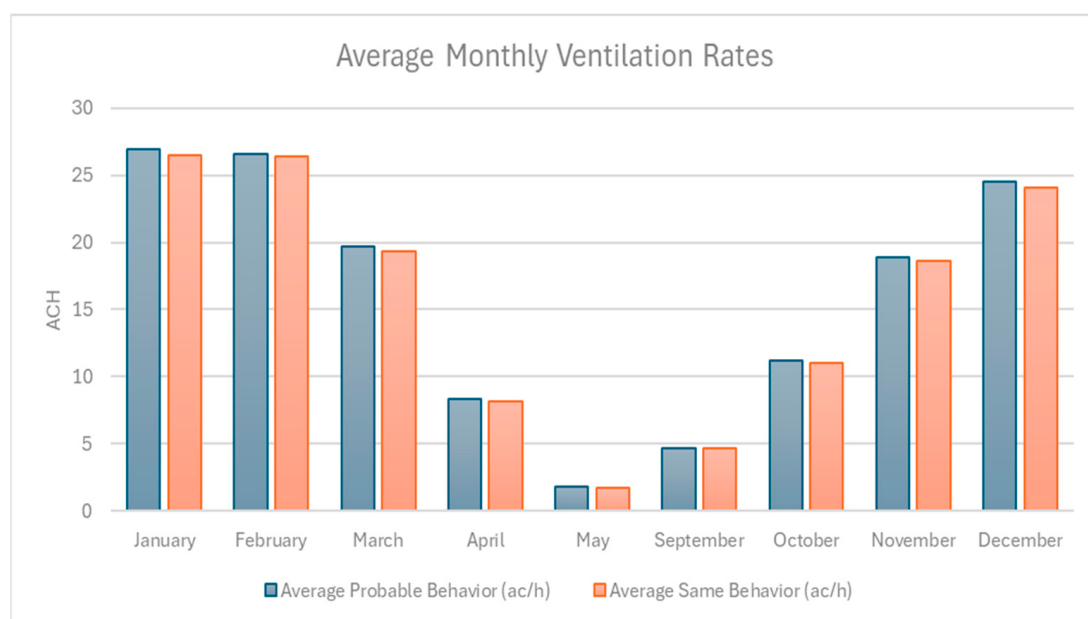


Figure 5. Natural-ventilation rates across configurations, SB (Scenario A).

These gains ranged from +0.9% to +4.0%, with the highest improvements seen in cooler months like May, when strategic use of the west-facing window contributed to better airflow. These findings indicate that while the configurations themselves already support robust natural airflow, occupant engagement can further enhance performance, especially during transitional times of day like early evening.

Solar gain also followed a seasonal trend, with the highest values recorded in summer. In December, Configuration 5 reached a peak of 707.88 kWh, largely due to its large glazed east-facing surface and favorable morning solar angles. High solar gain was also observed in January and February, with levels exceeding 690 kWh across several configurations. These conditions support passive heating during cooler months but may increase thermal load in summer if not mitigated through shading or occupant action. Notably, increased

solar gain in February aligned with higher NV rates, suggesting a behavioral response, that is, occupants opening windows more to counteract heat buildup. Detailed monthly comparisons of ventilation and solar gain are presented in Table 13.

Table 13. Ventilation and solar gain across configurations (Scenario A).

Month	Highest NV (ACH) (Config.)	Lowest NV (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	27.22 (5)	25.40 (6)	26.53	26.94	+1.5%	675.85	692.78 (5)	651.07 (6)
Feb	27.08 (5)	25.27 (6)	26.37	26.62	+0.9%	588.15	602.76 (5)	567.72 (6)
Mar	19.90 (5)	18.44 (6)	19.30	19.65	+1.8%	502.96	515.37 (5)	484.88 (6)
Apr	8.29 (3)	7.83 (6)	8.16	8.36	+2.5%	324.56	332.28 (5)	313.24 (6)
May	1.80 (5)	1.65 (6)	1.76	1.83	+4.0%	252.71	259.14 (5)	243.35 (6)
Sep	4.75 (3)	4.35 (6)	4.64	4.70	+1.3%	426.45	437.02 (5)	412.11 (6)
Oct	11.34 (5)	10.60 (6)	11.05	11.22	+1.5%	531.93	543.68 (5)	514.41 (6)
Nov	19.00 (5)	17.90 (6)	18.63	18.85	+1.2%	624.50	638.66 (5)	603.80 (6)
Dec	24.93 (5)	23.05 (6)	24.11	24.51	+1.7%	691.49	707.88 (5)	667.50 (6)

The results analysis reinforces the significance of east–west window arrangements, which, when aligned with Melbourne’s wind and sun patterns, can deliver high levels of ventilation and solar access year-round. The influence of window size, orientation, and user interaction is evident in both airflow and thermal outcomes, highlighting the importance of integrating architectural and behavioral strategies in passive design. Overall, the table illustrates how east–west window arrangements can support high levels of both ventilation and solar gain, with design details (e.g., window sizing and placement) and occupant behavior both playing critical roles in optimizing performance.

3.2.2. Scenario B: 4.5 m × 2.6 m East and West Walls

Scenario B follows the same design and behavioral logic on a smaller wall, and while total airflow rates were naturally lower due to reduced window area, the seasonal patterns and behavioral responsiveness mirrored Scenario A. Peak ventilation again occurred in January (15.35 ACH), with the lowest average in May (0.91 ACH). A detailed summary of the peak, lowest, and average ACH values across all configurations for Scenario B is presented in Table 14.

Table 14. Natural-ventilation performance of east–west windows (Scenario B).

Configuration	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH) (Sep–May)
1	15.52 (January)	0.90 (May)	7.90
2	15.55 (January)	0.91 (May)	7.96
3	15.71 (January)	0.93 (May)	8.07
4	15.40 (January)	0.90 (May)	7.87
5	15.45 (January)	0.92 (May)	7.87
6	15.26 (January)	0.91 (May)	7.80
7	15.21 (January)	0.90 (May)	7.74
8	14.87 (January)	0.89 (May)	7.60
9	15.18 (January)	0.90 (May)	7.73

Figure 6 shows the average monthly ventilation rates (ACH) under SB and PV scenarios, highlighting consistently higher airflow under PB during transitional months such as April, May, September, and October, while ventilation rates are nearly identical during the summer months (January–February) when environmental conditions strongly drive

window use. This pattern emphasizes the influence of adaptive occupant behavior in enhancing natural ventilation during milder periods when passive airflow might otherwise be limited.

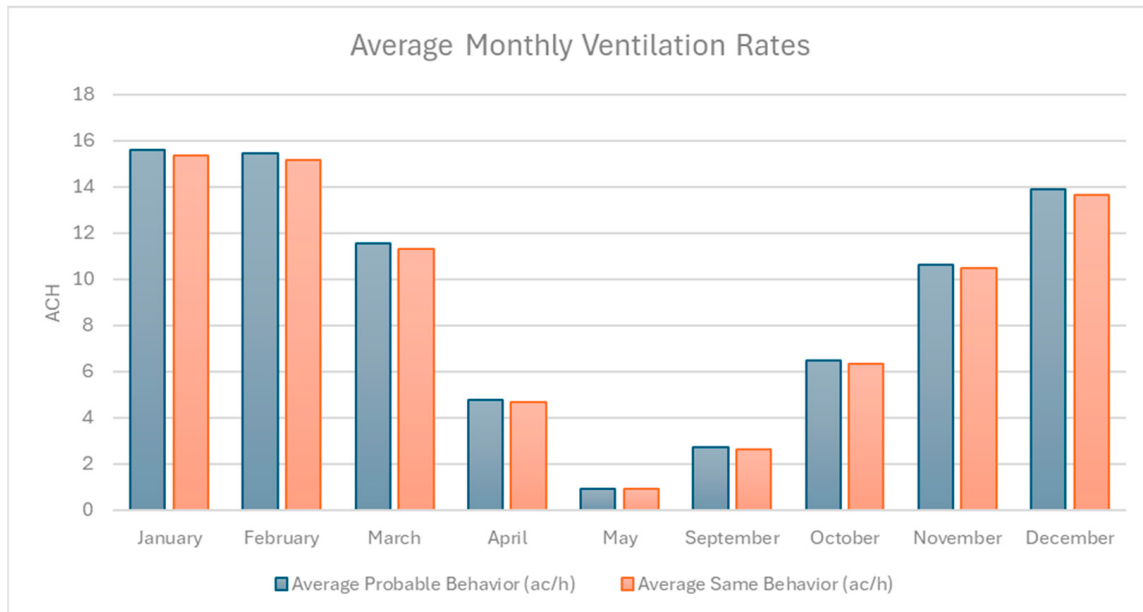


Figure 6. Natural-ventilation rates across configurations, SB (Scenario B).

Solar gain values were naturally lower in Scenario B due to smaller window areas but were still substantial, reaching 438.28 kWh in December. These levels are sufficient to influence thermal comfort and occupant decisions around window usage or shading devices, highlighting the link between passive solar exposure and user behavior. As shown in Table 15, ventilation performance under the PB model consistently exceeded that of the SB model across all months, with gains ranging from +1.4% in November to +3.3% in May. The highest absolute ventilation occurred in January and February, reflecting favorable summer conditions, while the largest behavioral impact was observed in transitional months like April, May, and September, when PB strategies helped extend ventilation during periods of moderate external temperatures. These findings underscore the critical role of occupant adaptability in enhancing natural ventilation during milder conditions, when default schedules may fall short of maximizing airflow potential.

Table 15. Ventilation and solar gain under SB and PB models (Scenario B).

Month	Highest NV Probable (ACH) (Config.)	Lowest NV Probable (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	15.71 (3)	14.87 (8)	15.35	15.62	+1.8%	421.33	428.61 (3)	411.11 (8)
Feb	15.49 (3)	14.65 (8)	15.14	15.45	+2.0%	367.55	373.29 (3)	358.56 (8)
Mar	11.64 (3)	11.04 (8)	11.31	11.54	+2.0%	313.62	318.93 (3)	306.37 (8)
Apr	4.84 (3)	4.52 (8)	4.67	4.79	+2.6%	202.74	206.07 (3)	198.15 (8)
May	0.93 (3)	0.89 (8)	0.91	0.94	+3.3%	157.65	160.58 (3)	153.94 (8)
Sep	2.72 (5)	2.55 (9)	2.64	2.71	+2.7%	266.40	270.89 (3)	260.51 (8)
Oct	6.50 (3)	6.12 (8)	6.33	6.47	+2.2%	332.32	337.49 (3)	325.42 (8)
Nov	10.78 (3)	10.14 (8)	10.49	10.64	+1.4%	389.68	395.90 (3)	381.66 (8)
Dec	14.06 (3)	13.18 (8)	13.64	13.89	+1.8%	431.23	438.28 (3)	421.61 (8)

3.2.3. Discussion: Design Implications and Behavioral Insights

Design Story 2 underscores the value of east–west window configurations for effective cross-ventilation, leveraging larger east-facing windows to harness morning breezes and smaller west-facing windows for afternoon airflow. Scenario A’s larger walls boost ventilation, making it well-suited for temperate climates with diurnal wind patterns, while Scenario B’s compact layout fits space-limited settings. Occupant adaptability, enabled by strategic window sizing, enhances natural ventilation (NV) and thermal comfort by aligning with daily wind cycles.

The configuration’s strength lies in its synergy with natural occupant routines, favoring east windows in the morning and west windows later in the day. This demonstrates that windows should be purposefully placed and proportioned to complement how people live, not just maximize size. By encouraging proactive window use, this design improves ventilation efficiency and strengthens occupants’ connection to their surroundings, a cornerstone of human-centered passive design.

3.3. Design Story 3: Two South-Facing Windows 45%

Design Story 3 explores a single-sided ventilation strategy using two south-facing windows with a combined WWR of 45%, aiming to leverage Melbourne’s diffuse daylight and stable breezes while minimizing direct solar exposure. In Scenario A, the ten configurations (Table 16) explore a range of window dimensions to balance daylight quality and airflow. Configurations 1 to 5 feature evenly sized, progressively taller windows that promote consistent ventilation and deeper daylight penetration, particularly Configuration 5, which uses the tallest windows (2.4×2.25 m) for maximum light reach with moderate ACH. In contrast, Configurations 6 to 10 adopt asymmetrical window sizes to fine-tune airflow and glare control; for example, Configuration 6 combines a wider secondary window for cross-breezes with a smaller primary one for daylight modulation. In Scenario B (Table 17), where wall area is constrained, the focus shifts to achieving performance through compact and functionally distinct window pairs. Symmetrical setups (e.g., Configuration 1) ensure balanced airflow and daylight, while asymmetrical designs like Configuration 5 and 8 employ one larger window to enhance ventilation and another narrower one to limit glare or overheating. These configurations demonstrate that carefully proportioned south-facing windows can effectively support both thermal comfort and visual quality, even within spatial limitations.

Table 16. Window configurations: Design Story 3, Scenario A.

Config	Window 1 (H × W, m)	Window 2 (H × W, m)	Ventilation/Lighting Impact
1	1.7 × 3.2	1.7 × 3.2	Balanced daylight; even airflow with wide windows.
2	1.8 × 3.05	1.8 × 3.05	Slightly taller windows enhance light diffusion; good ACH.
3	2.0 × 2.7	2.0 × 2.7	Taller windows push daylight deeper; consistent airflow.
4	2.2 × 2.45	2.2 × 2.45	Tall windows reduce artificial lighting needs; effective ventilation.
5	2.4 × 2.25	2.4 × 2.25	Maximized height for deep light penetration; moderate ACH.
6	1.7 × 2.6	1.7 × 3.8	Larger window drives deep light; smaller aids cross-breezes.
7	1.8 × 2.0	1.8 × 4.0	Larger window boosts ventilation; smaller controls glare.

Table 16. Cont.

Config	Window 1 (H × W, m)	Window 2 (H × W, m)	Ventilation/Lighting Impact
8	2.0 × 2.15	2.0 × 3.3	Larger window maximizes airflow; smaller regulates light.
9	2.2 × 1.7	2.2 × 3.3	Larger window dominates light/ventilation; smaller controls glare.
10	2.4 × 1.8	2.4 × 2.75	Taller windows flood light; smaller moderates sunlight.

Table 17. Window configurations: Design Story 3, Scenario B.

Config	Window 1 (H × W, m)	Window 2 (H × W, m)	Ventilation/Lighting Impact
1	2.0 × 1.75	2.0 × 1.75	Equal dimensions ensure even daylight and airflow.
2	1.8 × 1.95	1.8 × 1.95	Shorter windows support light penetration; moderate ACH.
3	1.75 × 2.0	1.75 × 2.0	Optimized for glare control; effective ventilation.
4	2.4 × 1.45	2.4 × 1.45	Tall windows deliver deep light; narrow width limits airflow.
5	2.0 × 1.15	2.0 × 2.3	Wider window boosts ventilation; narrower controls glare.
6	1.8 × 1.3	1.8 × 2.6	Larger window drives light/airflow.
7	2.4 × 1.0	2.4 × 2.0	Tall design aids light diffusion; smaller controls sunlight.
8	1.7 × 1.35	1.7 × 2.7	Larger window focuses on airflow; smaller manages heat.
9	2.0 × 1.4	2.0 × 2.1	Balanced windows ensure daylight and ventilation.
10	1.7 × 1.65	1.7 × 2.4	Larger window aids ventilation; smaller controls light.

3.3.1. Scenario A: 7.0 m × 2.6 m

NV rates vary seasonally, peaking in summer due to higher temperatures and stronger winds and declining in late autumn as outdoor conditions cool and wind speeds drop. As shown in Table 18, January consistently records the highest ACH values across all design stories, with Story 5 achieving the peak rate of 30.07 ACH, followed by Stories 10, 7, and 8, all of which feature dual or cross-orientation window configurations that enhance airflow. In contrast, May marks the lowest ventilation rates for all stories, with Story 9 dropping to just 1.57 ACH, reflecting limited wind exposure and lower occupant-driven window use. Average ACH values across the stories range from 11.68 (Story 9) to 16.67 (Story 5), reinforcing the performance advantage of designs that combine favorable orientations and larger or more operable window areas. These results highlight how orientation, configuration, and occupant behavior interact to shape seasonal ventilation outcomes, with cross-ventilation setups offering the most robust performance year-round.

Table 18. Ventilation and solar gain—Design Story 2, Scenario B (SB and PB).

Story	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH)
Story 1	24.79 (January)	1.70 (May)	13.40
Story 2	24.76 (January)	1.69 (May)	13.38
Story 3	24.08 (January)	1.63 (May)	12.96

Table 18. Cont.

Story	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH)
Story 4	24.99 (January)	1.73 (May)	13.57
Story 5	30.07 (January)	2.27 (May)	16.67
Story 6	23.21 (January)	1.58 (May)	12.49
Story 7	27.82 (January)	1.91 (May)	15.27
Story 8	27.60 (January)	1.94 (May)	15.17
Story 9	21.76 (January)	1.57 (May)	11.68
Story 10	28.18 (January)	1.91 (May)	15.42

Configurations with taller, evenly sized windows outperform others, leveraging vertical openings to enhance stack-driven airflow. As shown in Figure 7, January and February exhibit the highest average ACH, reflecting favorable environmental conditions, while May records the lowest, regardless of behavior model. Across most months, the PB model consistently results in slightly higher ventilation than the SB scenario, with the largest differences observed during transitional months such as April, September, and October, when adaptive responses to thermal comfort are more variable. The improvement under PB, although modest, reflects enhanced occupant responsiveness, particularly in periods with moderate temperatures when ventilation is most beneficial but not guaranteed by default schedules. This highlights the importance of designing window configurations that not only facilitate stack-driven airflow but also align with realistic occupant behavior patterns throughout the year.

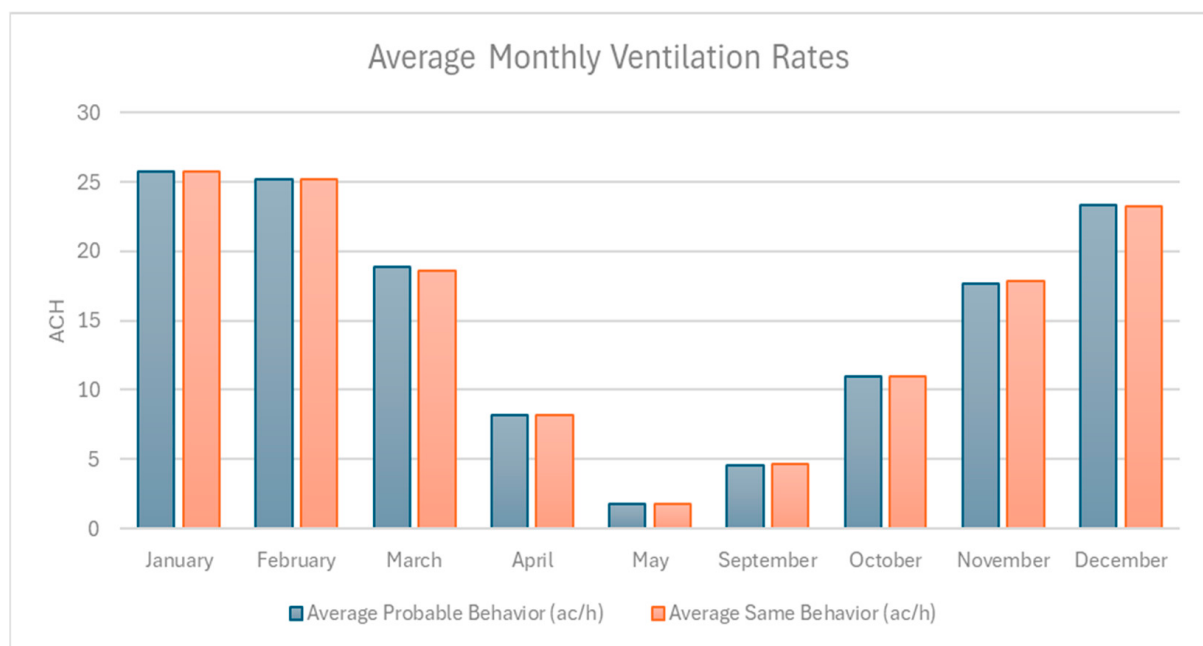


Figure 7. Natural-ventilation rates across configurations, SB (Scenario A).

Solar gain is highest in December and January, with wide and tall windows, particularly Configuration 5, capturing the most heat, peaking at 708.39 kWh in both months (Table 19). This substantial thermal input enhances contributes positively to indoor comfort during cooler periods, but it also increases the risk of overheating in summer if not mitigated through shading or strategic window operation. Interestingly, while solar gain peaks align with high natural ventilation rates, the average ventilation under PB does not always increase proportionally—in January, for example, ventilation slightly decreased

(−0.2%) under PB compared to SB, despite the high solar load. This suggests that elevated indoor temperatures may encourage window opening, but behavioral nuances such as comfort thresholds, glare, or noise sensitivity can moderate that response. Overall, these results highlight the need to pair high-performing south-facing window designs with appropriate solar control strategies to balance passive heating benefits with occupant comfort year-round.

Table 19. Ventilation and solar gain—Design Story 3, Scenario A (SB and PB).

Month	Highest NV Probable (ACH) (Config.)	Lowest NV Probable (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	30.07 (5)	21.76 (9)	25.75	25.70	−0.2%	626.69	708.39 (5)	535.21 (9)
Feb	29.64 (5)	21.46 (9)	25.20	25.22	+0.1%	547.62	603.69 (5)	466.66 (9)
Mar	21.86 (5)	15.92 (9)	18.61	18.89	+1.5%	467.46	515.69 (5)	398.63 (9)
Apr	9.62 (5)	7.00 (9)	8.16	8.18	+0.2%	302.59	332.61 (5)	257.57 (9)
May	2.27 (5)	1.57 (9)	1.79	1.78	−0.6%	233.97	259.52 (5)	199.95 (9)
Sep	5.47 (5)	3.87 (9)	4.64	4.56	−1.7%	398.31	437.60 (5)	338.82 (9)
Oct	12.84 (5)	9.20 (9)	10.98	11.00	+0.2%	499.50	543.92 (5)	423.22 (9)
Nov	20.99 (5)	14.89 (9)	17.82	17.66	−0.9%	585.16	638.89 (5)	496.55 (9)
Dec	27.36 (5)	19.46 (9)	23.27	23.36	+0.4%	645.04	708.39 (5)	548.90 (9)

Scenario A’s symmetrical layout promotes balanced airflow and spatial comfort. Occupants engage more actively with both windows during midday and early afternoon, especially when external conditions support comfortable indoor temperatures.

Although some months, e.g., January, May, September, and November, show slightly lower NV values under PB, these variations reflect nuanced behavioral responses such as shorter opening durations due to thermal comfort, noise, or privacy concerns rather than design inefficiencies.

3.3.2. Scenario B: 4.5 m × 2.6 m

Table 20 shows the NV performance of nine south-facing window configurations in Scenario B (4.5 m × 2.6 m wall) under the SB model. It reports the peak, lowest, and average ACH values between September and May for each configuration. The highest ventilation rate was observed in February, reaching 16.63 ACH in Configuration 12, while the lowest rates occurred in May, with values as low as 0.85 ACH in Configuration 14. Despite the reduced wall size, average ventilation performance remained consistent across all configurations, ranging from 8.90 to 8.94 ACH, indicating that well-designed south-facing windows can provide stable and effective airflow even in compact spaces.

Despite the lower ventilation potential, occupant behavior still played a meaningful role. When likely behaviors were factored in, such as opening windows at certain times of day or in response to comfort needs, modest improvements were seen, especially during mild months like May and October. These months showed relative gains of +0.8% to +2.9% compared to SB, suggesting people are more inclined to open windows when temperatures are comfortable and indoor comfort can be fine-tuned naturally.

In some months, however, the model showed slight decreases in ventilation under PB. These drops do not suggest a flaw in the design but rather reflect realistic tendencies: People do not always open windows when models assume they will. They might delay it until the room feels warm enough or avoid it due to noise, wind, or privacy concerns. These subtleties highlight how important it is to design for actual behavior, not just theoretical use. Figure 8 highlights this point, showing that ventilation under PB is slightly lower than SB in several months, including January, May, and September. These minor reductions suggest that when conditions are either already comfortable or marginally uncomfortable,

occupants may hesitate to act, even if the opportunity for ventilation exists. Thus, a user-responsive design should anticipate such hesitations and provide features, like operable window height, ease of access, or visual cues, that gently encourage beneficial window use without relying on idealized behavioral patterns.

Table 20. Natural-ventilation rates across stories, SB (Scenario B).

Configuration	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH) (Sep–May)
10	15.61 (February)	0.88 (May)	8.92
11	15.59 (February)	0.87 (May)	8.90
12	16.63 (February)	0.88 (May)	8.94
13	15.62 (February)	0.88 (May)	8.93
14	15.63 (February)	0.85 (May)	8.94
15	15.61 (February)	0.88 (May)	8.92
16	15.60 (February)	0.87 (May)	8.91
17	16.18 (February)	0.88 (May)	8.92
18	15.62 (February)	0.88 (May)	8.93

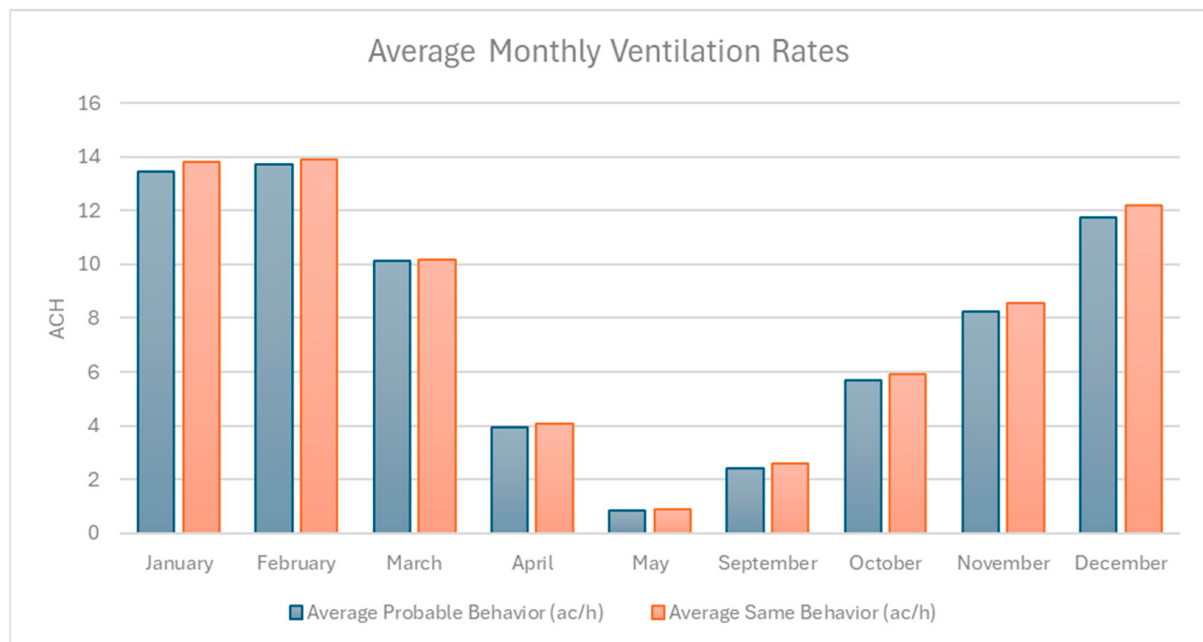


Figure 8. Story 3, Scenario B, average monthly ventilation rates (ACH), SB vs. PB.

Solar gain also followed a similar pattern. Though overall heat gain was lower than in Scenario A, it was still significant, peaking at around 408.92 kWh in December. Taller window configurations captured more sunlight, especially around midday, helping to passively warm interiors during cooler months. This natural warmth often meant windows were opened later in the day, after indoor temperatures had already risen—a subtle but telling sign of how solar gain can shape how and when people engage with their space. As shown in Table 21, ventilation under the PB model was slightly lower than SB in most months, with declines up to -6.2% in September. This suggests that despite increased solar gains, occupants may hesitate to open windows due to comfort or contextual factors, reinforcing the need for user-friendly window designs that align with real-world behavior.

Table 21. Ventilation and solar gain—Design Story 3, Scenario B (SB and PB).

Month	Highest NV Probable (ACH) (Config.)	Lowest NV Probable (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	16.47 (12)	15.95 (17)	13.82	13.47	−2.5%	369.65	424.69 (3)	334.32 (5)
Feb	16.63 (12)	16.18 (17)	13.91	13.74	−1.2%	322.39	370.33 (3)	291.50 (5)
Mar	11.89 (12)	11.49 (17)	10.17	10.11	−0.6%	275.41	316.28 (3)	249.11 (5)
Apr	4.76 (12)	4.59 (17)	4.09	3.92	−4.2%	178.04	204.54 (3)	161.06 (5)
May	0.88 (10)	0.88 (17)	0.88	0.85	−3.4%	138.41	158.99 (3)	125.21 (5)
Sep	2.99 (12)	2.89 (17)	2.57	2.41	−6.2%	234.12	268.99 (3)	211.78 (5)
Oct	6.86 (12)	6.63 (17)	5.90	5.68	−3.7%	292.26	335.83 (3)	264.34 (5)
Nov	9.98 (12)	9.65 (17)	8.56	8.25	−3.6%	342.86	393.87 (3)	309.99 (5)
Dec	14.25 (12)	13.76 (17)	12.20	11.75	−3.7%	378.88	435.32 (3)	342.72 (5)

Overall, Scenario B underscores the idea that good design is not just about maximizing performance on paper; it is about aligning with how people actually live. Even small shifts in behavior can shape how effectively a space breathes. Designing windows that naturally encourage engagement by being easy to use, well-placed, and responsive to daylight and temperature can make all the difference in how a space feels and functions day to day.

3.3.3. Discussion: Design Implications and Behavioral Insights

One of the standout findings is that symmetry supports user perception of balance and encourages even use of windows, making the act of opening feel intuitive. Furthermore, the alignment with solar paths favoring midday and early afternoon gain means that this configuration can effectively reduce heating needs in winter and still offer good ventilation if overheating is addressed through timing or shading.

This design story offers a practical example of how symmetrical, south-facing windows can serve as both a thermal comfort tool and a behavioral cue. By placing equal openings along a single orientation that receives stable solar exposure, the design encourages occupants to open both windows simultaneously, maximizing perceived and actual airflow. The absence of extreme sun angles unlike east or west windows supports prolonged, low-glare usage ideal for work or relaxation spaces.

From a design perspective, this configuration demonstrates that user-friendly ventilation does not necessarily require dynamic geometry or multi-orientation setups. Instead, it shows how clear, simple design aligned with occupant habits and climate-driven needs can foster better interaction with the building envelope. The south-facing orientation becomes a mediator of light, heat, and airflow, and the behavioral data suggests that when such windows are comfortable to use and visually balanced, occupants are more likely to engage with them throughout the year.

3.4. Design Story 4: North–South Window Configuration

Design Story 4 examines two north-facing windows, 25% WWR each, and one large south-facing window, 40% WWR, on opposing walls. The primary design intent was to optimize cross-ventilation by establishing airflow between opposing walls while simultaneously taking advantage of diffuse daylight from the north and solar warmth from the south especially beneficial during Melbourne’s cooler seasons. As shown in Tables 22 and 23 configurations with taller south-facing windows (e.g., Configs 1, 4, and 5 in Scenario A) consistently improved both daylight penetration and airflow exhaust, while balanced or slightly narrower north windows controlled glare and managed heat entry. In Scenario B, with a reduced wall height, smaller north windows still enabled airflow, but their lower vertical opening area slightly reduced ventilation effectiveness. Overall, combinations

that paired proportional north openings with tall, strategically positioned south windows (e.g., Configs 7 and 10) maintained steady cross-ventilation and lighting, confirming that orientation, sizing, and balance between opposing facades are key to maximizing passive comfort strategies.

Table 22. Window configurations: Design Story 4, Scenario A.

Config	2× North Windows (H × W, m)	South Window (H × W, m)	Ventilation/Lighting Impact
1	2.4 × 2.0	2.4 × 3.0	Balanced north windows; tall south enhances daylight/ventilation.
2	2.2 × 2.0	2.2 × 3.3	Shorter south balances light; north ensures cross-ventilation.
3	2.0 × 2.3	2.0 × 3.6	Larger north aids airflow; tall south exhausts heat.
4	1.8 × 2.6	1.8 × 4.0	Compact north minimizes glare; large south ensures ventilation.
5	1.6 × 2.8	1.6 × 4.6	Narrow north controls glare; large south enhances comfort.
6	1.6 × 2.9	2.2 × 3.3	Shorter north reduces heat; taller south aids daylight.
7	1.7 × 2.7	2.4 × 3.0	Balanced north airflow; tall south maximizes light/ventilation.
8	1.8 × 2.6	2.2 × 3.3	Taller north prioritizes ventilation; south enhances daylight.
9	1.6 × 2.9	2.4 × 3.0	Compact north controls glare; large south aids ventilation.
10	1.7 × 2.6	2.2 × 3.3	Proportional north aids airflow; tall south enhances cooling.

Table 23. Window configurations: Design Story 4, Scenario B.

Config	2× North Windows (H × W, m)	South Window (H × W, m)	Ventilation/Lighting Impact
1	2.4 × 1.2	2.4 × 1.9	Balanced dimensions ensure ventilation; south aids light.
2	2.2 × 1.4	2.2 × 3.3	Shorter south balances light; north ensures ventilation.
3	2.2 × 1.4	2.0 × 2.4	South reduces glare; north maintains ventilation.
4	1.8 × 1.6	1.8 × 2.6	Narrow north minimizes gain; south ensures light.
5	1.6 × 1.8	1.6 × 2.9	Narrow north reduces glare; tall south aids ventilation.
6	1.6 × 1.8	2.2 × 2.0	Shorter north reduces heat; taller south enhances light.
7	1.7 × 1.7	2.4 × 2.0	Balanced north airflow; tall south aids light/ventilation.
8	1.8 × 1.7	2.2 × 2.1	Taller north prioritizes ventilation; south enhances light.
9	1.6 × 1.8	2.4 × 2.0	Compact north controls glare; south aids ventilation.
10	1.7 × 1.7	2.2 × 2.2	Proportional north aids airflow; south enhances cooling.

3.4.1. Scenario A: 7 m × 2.6 m North and South Walls

The NV rates across configurations in Scenario A display clear seasonal variation. Rates peak in late summer, driven by stronger winds, warmer temperatures, and occupants' increased tendency to open windows. They drop in late autumn as wind speeds diminish and temperatures cool. Configurations with larger north-facing windows consistently outperform others, highlighting the benefit of increased window area in capturing prevailing winds for cross-ventilation. Table 24 summarizes these monthly ventilation patterns under SB.

Table 24. Natural-ventilation rates across stories, SB (Scenario A).

Configurations	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH)
A1	36.24 (February)	3.38 (May)	21.48
A2	35.95 (February)	3.33 (May)	21.21
A3	36.18 (February)	3.35 (May)	21.56
A4	36.05 (February)	3.33 (May)	21.33
A5	35.82 (February)	3.30 (May)	21.01
A6	35.92 (February)	3.33 (May)	21.14
A7	35.93 (February)	3.36 (May)	21.14
A8	36.10 (February)	3.35 (May)	21.36
A9	35.76 (February)	3.34 (May)	21.07
A10	35.75 (February)	3.32 (May)	20.93

When occupant behavior is adjusted to reflect probable patterns such as prioritizing morning inflow via north-facing windows and evening exhaust through south-facing ones, NV rates improve further. Configurations where occupants make fewer or smaller window adjustments, particularly during midday, tend to show reduced performance. This reflects common behaviors such as managing indoor heat or glare. As shown in Figure 9, ventilation is significantly higher under the PB model, particularly in warmer months like January, February, and December, where adaptive use of openings yields up to 3–5 ACH more than the SB scenario. This gap highlights how dynamic, context-aware behavior can substantially enhance natural ventilation performance across seasons.

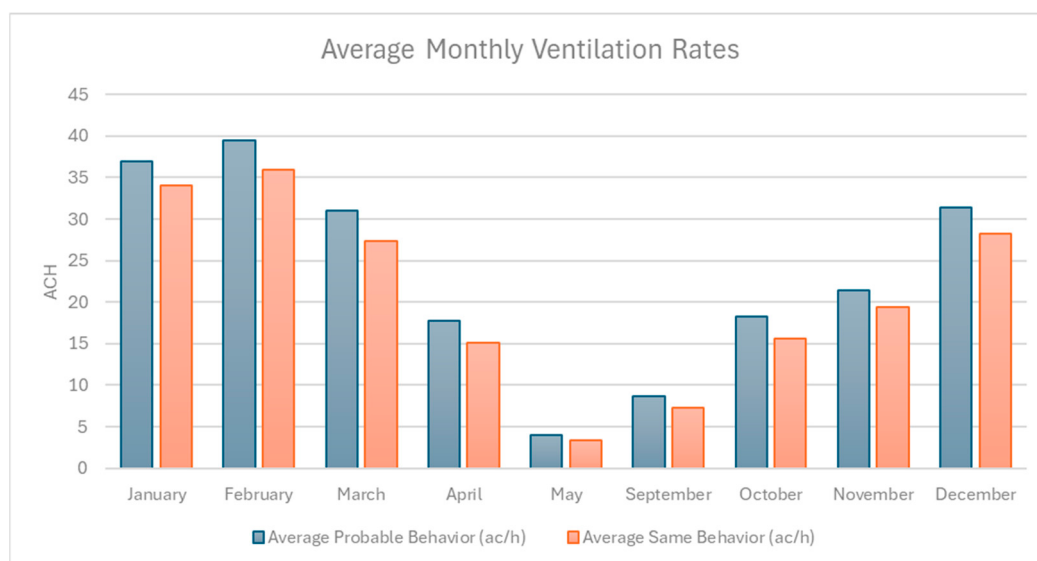


Figure 9. Natural-ventilation rates across configurations, SB (Scenario A).

Solar gain peaks in February across all configurations. Configurations with wider south-facing windows capture more solar heat, which aligns with increased NV activity in that month. This suggests that higher indoor temperatures may encourage occupants to open windows for cooling, supporting the link between solar gain and adaptive ventilation behavior. This balance can be further optimized with shading devices to modulate thermal comfort without compromising airflow.

Table 25 provides a clear summary of monthly NV and solar gain outcomes for Scenario A under both Same and PB models. Compared to the Same, the PB model results in consistent improvements in NV rates across all months, with increases ranging from +7.6% in December to a substantial +21.6% in May.

Table 25. Ventilation and solar gain—Design Story 4, Scenario A (SB and PB).

Month	Highest NV Probable (ACH) (Config.)	Lowest NV Probable (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	35.90 (1)	35.75 (10)	34.04	37.00	+8.7%	423.94	427.89 (3)	420.58 (10)
Feb	36.24 (1)	35.75 (10)	35.97	39.41	+9.6%	421.31	426.44 (3)	418.49 (10)
Mar	25.60 (1)	25.40 (10)	27.31	31.00	+13.5%	547.37	553.22 (3)	541.82 (10)
Apr	10.25 (1)	10.15 (10)	15.09	17.71	+17.4%	515.99	521.83 (3)	510.71 (10)
May	3.38 (1)	3.32 (10)	3.34	4.06	+21.6%	534.33	541.11 (3)	529.02 (10)
Sep	8.55 (1)	8.45 (10)	7.29	8.64	+18.5%	532.32	538.21 (3)	526.98 (10)
Oct	15.35 (1)	15.25 (10)	15.63	18.28	+16.9%	487.98	493.01 (3)	483.56 (10)
Nov	22.50 (1)	22.30 (10)	19.39	21.38	+10.3%	419.25	423.27 (3)	415.71 (10)
Dec	30.20 (1)	30.00 (10)	28.22	31.37	+7.6%	431.23	434.96 (3)	428.02 (10)

These improvements suggest that occupants are more inclined to interact with windows when comfort conditions are favorable and window operation feels intuitive and effective.

Overall, the cross-orientation layout of Scenario A supported natural airflow regulation across seasons. The size and vertical placement of the south-facing window encouraged its use during periods of heat buildup, while the dual north-facing windows remained consistently accessible for fresh air intake, especially during milder and humid conditions. The resulting ventilation paths were stable, long, and intuitively activated by occupant behavior, reflecting strong synergy between form and function.

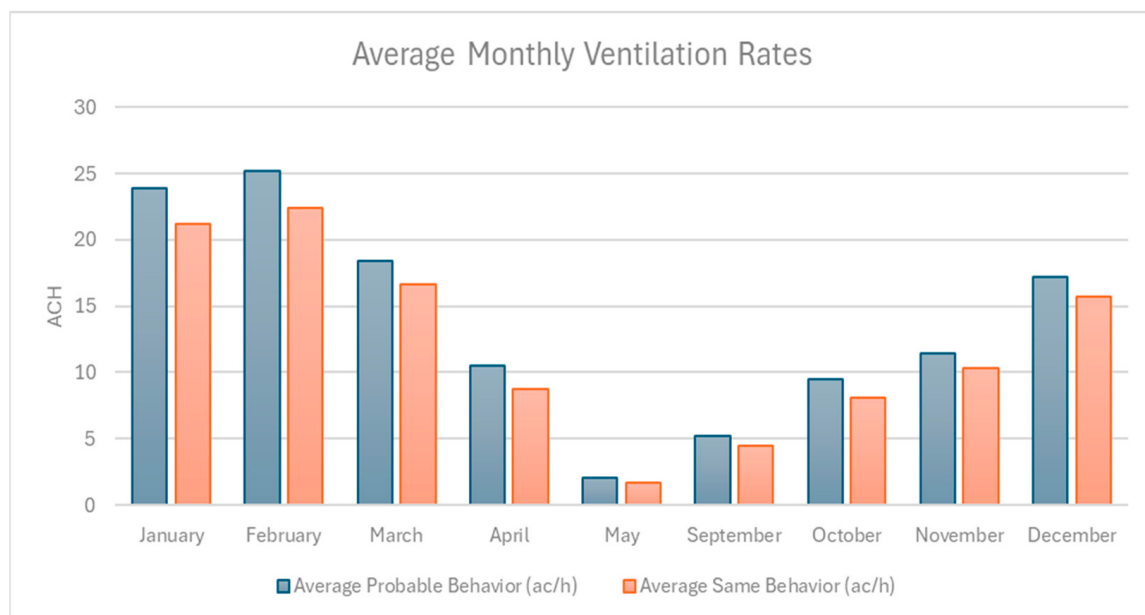
3.4.2. Scenario B: 4.5 m × 2.6 m North and South Walls

In Scenario B, the same window layout was applied to shorter 4.5 m walls, maintaining the original WWRs. As expected, ventilation performance declined slightly due to the reduced wall surface area available for airflow. Table 26 presents the natural ventilation outcomes across configurations under SB conditions. Peak ventilation occurred in February, with Configuration A6 reaching 23.75 ACH, while May consistently recorded the lowest rates across all configurations, dipping as low as 1.60 ACH in A5. Average ventilation rates ranged from 10.47 ACH to 12.09 ACH. Behaviorally, probable interactions continued to modestly enhance performance, with relative gains of around +0.9% to +3.1%, particularly during transitional months like March and October, when indoor comfort needs prompted more deliberate window use. These subtle behavioral adjustments underscore the impact of user decisions in optimizing airflow within spatial constraints.

Table 26. Natural ventilation rates across stories, SB (Scenario B).

Configuration	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH) (Sep–May)
A1	21.41 (January)	1.87 (May)	11.22
A2	22.58 (February)	1.63 (May)	11.45
A3	22.30 (February)	1.64 (May)	11.05
A4	22.44 (February)	1.72 (May)	11.33
A5	20.87 (February)	1.60 (May)	10.47
A6	23.75 (February)	1.77 (May)	12.09
A7	22.12 (February)	1.64 (May)	10.88
A8	22.57 (February)	1.75 (May)	11.28
A9	22.26 (February)	1.66 (May)	11.11

The south-facing window continued to deliver strong solar gains, reaching 474.85 kWh in December, a meaningful figure given the smaller room volume and surface area. This gain improved thermal conditions in winter and shoulder seasons, often leading occupants to delay window opening until later in the afternoon, once internal heat gain had leveled off. This deferred engagement points to a more strategic interaction pattern, wherein users modulate ventilation not only for airflow but also for thermal preservation. As shown in Figure 10, this behavioral adaptation led to consistently higher average monthly ventilation rates under PB across nearly all months. Notably, ventilation improvements were especially evident in March, April, and December, confirming that even slight behavioral shifts can enhance natural ventilation effectiveness in compact spaces.

**Figure 10.** Natural-ventilation rates across configurations, SB (Scenario B).

Although airflow capacity was reduced compared to Scenario A, Scenario B retained effective thermal regulation and ventilation bursts, particularly when all three windows were operated in coordination. The slightly compressed spatial dimensions made window timing more critical; short openings had stronger impacts on room conditions due to the smaller volume, and users appeared to adjust accordingly. As shown in Table 27, Config. 6 consistently outperformed others across all months, achieving the highest NV rates, peaking at 23.75 ACH in February and maintaining strong solar gains, with December reaching 287.18 kWh. In contrast, Config. 5 showed the weakest performance, with the

lowest ACH values in nearly every month. PB increased ventilation rates by up to 19.8% in April and over 12% in the summer months, suggesting that adaptive window operation, even in a more compact layout, can significantly boost performance. The pairing of well-sized north and south openings enabled rapid thermal responses, particularly when solar gain exceeded 330 kWh during the cooler months, further supporting delayed but strategic occupant engagement.

Table 27. Highest and lowest ventilation performers by month for PB (Scenario B).

Month	Highest NV (ACH) (Config.)	Lowest NV (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	22.42 (6)	19.65 (5)	21.23	23.86	+12.4%	269.77	280.93 (6)	263.57 (1)
Feb	23.75 (6)	20.87 (5)	22.36	25.18	+12.6%	268.43	277.28 (6)	261.87 (1)
Mar	17.48 (6)	15.56 (5)	16.67	18.43	+10.6%	346.27	356.11 (6)	338.75 (1)
Apr	9.13 (6)	8.52 (10)	8.78	10.52	+19.8%	326.68	333.73 (6)	318.47 (1)
May	1.87 (1)	1.60 (5)	1.72	2.05	+19.2%	338.21	344.38 (6)	329.53 (1)
Sep	4.58 (6)	4.31 (5)	4.48	5.22	+16.5%	337.44	345.46 (6)	329.07 (1)
Oct	8.41 (6)	7.76 (5)	8.12	9.48	+16.7%	309.82	318.88 (6)	302.05 (1)
Nov	10.96 (6)	9.75 (5)	10.36	11.41	+10.1%	266.79	277.31 (6)	260.43 (1)
Dec	16.63 (6)	14.91 (5)	15.74	17.21	+9.3%	274.85	287.18 (6)	268.53 (1)

Discussion: Design Implications and Behavioral Insights

Design Story 4 illustrates how cross-ventilation can be effectively achieved through thoughtful window placement on opposing walls. The combination of two north-facing windows and one larger south-facing window created a natural airflow loop that aligned with daily occupant routines inviting cool air in the morning and exhausting warm air in the evening. This intuitive setup encouraged more frequent window use and improved overall ventilation, particularly in larger rooms.

Scenario A, with its longer walls, better supported airflow and daylighting, while Scenario B demonstrated that the same configuration could still work in smaller spaces, though with slightly reduced effectiveness. Occupant behavior played a key role: when windows were used proactively, comfort improved noticeably. However, if windows were kept closed due to glare or external conditions, the benefits diminished.

Overall, this design highlights the importance of aligning architectural elements with natural patterns and occupant habits. By supporting easy and meaningful interaction, the window configuration promoted both thermal comfort and energy-efficient performance without relying on complex systems

3.5. Design Story 5: North–East Window Configuration

Design Story 5 investigates a system featuring one large north-facing window (40% WWR) and two east-facing windows (25% WWR each). This configuration strategically utilizes Melbourne’s prevailing morning sunlight and wind conditions to enhance cross-ventilation and daylight distribution. The study includes ten configurations for Scenario A and ten for Scenario B, each varying window dimensions to evaluate their combined effects on ventilation, daylight, and occupant interaction—details are provided in Tables 28 and 29. In these north–east arrangements, occupants are likely to open east-facing windows during early hours to capture cool air and bright morning light, adjust openings around midday to manage heat and glare, and rely more on the north-facing window in the afternoon and evening for exhaust. This adaptive behavior reflects daily rhythms of thermal comfort, illumination needs, and privacy management, further highlighting the potential of dynamic façade systems.

Table 28. Window configurations: Design Story 5, Scenario A.

Config	North Window (H × W, m)	East Windows (Each, H × W, m)	Ventilation/Lighting Impact
1	2.4 × 3.05	2.4 × 1.2	East provides bright AM light; north balances daylight.
2	2.2 × 3.3	2.2 × 1.35	Tall north distributes soft light; east controls AM sun.
3	2.0 × 3.65	2.0 × 1.45	Moderately tall east aids light; north stabilizes illumination.
4	1.8 × 4.05	1.8 × 1.65	Extended north glazing aids light depth; east needs control.
5	1.6 × 4.55	1.6 × 1.85	Narrow north controls glare; east provides strong AM light.
6	2.2 × 3.3	1.6 × 1.85	Narrow east aids AM light; north reduces midday glare.
7	2.4 × 3.05	1.7 × 1.7	Wide north ensures consistent light; east boosts AM brightness.
8	2.2 × 3.3	1.8 × 1.65	Balanced north glow; east supplies ample AM daylight.
9	2.4 × 3.03	1.6 × 1.85	Wide north illuminates midday; east aids AM light.
10	2.2 × 3.3	1.7 × 1.7	Strong cross-ventilation; north stabilizes light.

Table 29. Window configurations: Design Story 5, Scenario B.

Config	North Window (H × W, m)	East Windows (Each, H × W, m)	Ventilation/Lighting Impact
1	2.4 × 1.95	2.4 × 1.9	North offers diffuse light; east boosts AM brightness.
2	2.2 × 2.15	2.2 × 2.05	Tall north and east ensure cross-ventilation; balanced light.
3	2.0 × 2.35	2.0 × 2.3	Tall east delivers AM light; north stabilizes illumination.
4	1.8 × 2.6	1.8 × 2.55	Tall windows aid vertical airflow; east produces intense AM light.
5	1.6 × 2.95	1.6 × 2.85	Narrow windows bring AM sun; north stabilizes light.
6	2.2 × 2.15	1.6 × 2.85	Large east sashes aid breeze; north moderates light.
7	2.4 × 1.95	1.7 × 2.65	Wide north fosters ventilation; east boosts AM light.
8	2.2 × 2.15	1.8 × 2.55	Quick air exchange; east bright in AM, north glare-free.
9	2.4 × 1.95	1.6 × 2.85	Wide north illuminates midday; east aids AM light.
10	2.2 × 2.15	1.7 × 2.65	Strong cross-ventilation; north stabilizes light.

3.5.1. Scenario A: 7 m × 2.6 m North Wall and 4.5 m × 2.6 m East Wall

NV rates in Scenario A exhibit seasonal variation, peaking in late summer when warmer temperatures, stronger winds, and increased occupant-window use align to enhance cross-ventilation. In contrast, rates decline in late autumn as outdoor conditions become less favorable. Among the various story configurations, those with wider north-facing windows consistently outperformed others, highlighting the role of window size

in facilitating effective exhaust in a cross-ventilation strategy. Table 30 illustrates that Configuration 2 achieved the highest average NV rate at 17.32 ACH, followed closely by Configurations 8 and 10. These layouts featured broader north-facing openings, reinforcing their contribution to sustained airflow. Conversely, Configuration 5 recorded the lowest average at 15.95 ACH, suggesting that narrower window setups may limit airflow potential despite similar east-facing inputs.

Table 30. Natural-ventilation rates across stories, SB (Scenario A).

Configuration	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH)
A1	23.81 (March)	5.36 (May)	16.22
A2	25.39 (March)	5.89 (May)	17.32
A3	23.86 (March)	5.39 (May)	16.25
A4	24.09 (March)	5.38 (May)	16.37
A5	23.66 (March)	5.30 (May)	15.95
A6	24.08 (March)	5.38 (May)	16.29
A7	23.73 (March)	5.38 (May)	16.07
A8	25.18 (March)	5.87 (May)	16.92
A9	24.06 (March)	5.43 (May)	16.24
A10	24.73 (March)	5.82 (May)	16.58

In Scenario A, where the layout prioritizes a wider north-facing façade and a narrower east-facing one, NV consistently performs well, particularly during the warmer months. March stands out with the highest average NV rate of 26.18 ACH under the “Probable” occupant behavior model, a significant improvement from the Same 24.36 ACH, marking a 7.5% increase. This trend is not isolated, other months like January and December also show notable gains of 7.1% and 11.1%, respectively, when occupants actively respond to their environment by opening windows at optimal times. Configuration 2 consistently yields the highest NV rates, peaking at 25.39 ACH in March, while Configuration 5 tends to underperform, showing the lowest values across most months. The data reinforces the effectiveness of a well-sized north-facing window acting as a strong exhaust pathway, especially when paired with strategic east-facing intake openings. As illustrated in Figure 11, PB outperforms SB in nearly all months, with the most pronounced improvements occurring during the shoulder seasons, March, September, and December, demonstrating how nuanced occupant interactions can significantly enhance ventilation outcomes even in designs with modest wall dimensions.

In Scenario A, solar gain tends to follow a predictable seasonal rhythm, with the highest values appearing in March. During this month, the average solar gain reached 578.86 kWh, peaking at 605.23 kWh in Configuration 2. This spike can largely be attributed to the larger north-facing windows, which allow more sunlight to pour into the space. As the indoor temperatures rise, it is natural for occupants to respond by opening windows more frequently, increasing NV to stay comfortable. While this extra sunlight can be beneficial for boosting airflow, it also presents a challenge. Too much solar gain can lead to overheating, especially during peak sun hours. That is why it is important to consider solutions like shading devices or specially treated glazing to strike a balance between letting in light and maintaining a comfortable indoor environment.

Table 31 compares ventilation and solar gains across configurations in Design Story 5, Scenario A, under SB and PB. Configuration 2 consistently outperformed others in both ventilation and solar performance, achieving the highest NV rates in every month—peaking at 25.39 ACH in March—and the highest solar gains, reaching 605.23 kWh. In contrast,

Configuration 5 repeatedly recorded the lowest values for both metrics, highlighting its limited responsiveness to occupant behavior and less effective window sizing.

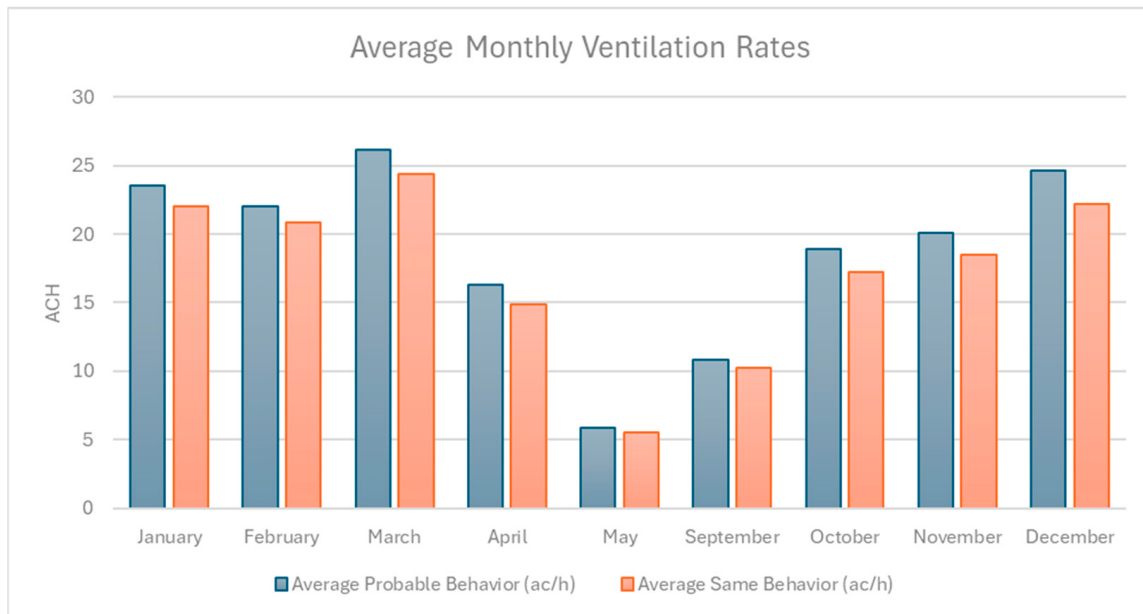


Figure 11. Story 5, Scenario A, average monthly ventilation rates (ACH), SB vs. PB.

Table 31. Ventilation and solar gain—Design Story 5, Scenario A (SB and PB).

Month	Highest NV Probable (ACH) (Config.)	Lowest NV Probable (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	22.72 (2)	21.29 (5)	22.00	23.57	+7.1%	485.17	502.49 (2)	472.70 (5)
Feb	21.77 (2)	20.38 (5)	20.88	22.05	+5.6%	491.50	510.64 (2)	479.15 (5)
Mar	25.39 (2)	23.66 (5)	24.36	26.18	+7.5%	578.86	605.23 (2)	564.66 (5)
Apr	15.63 (2)	14.42 (5)	14.90	16.28	+9.3%	506.61	531.74 (2)	494.55 (5)
May	5.89 (2)	5.30 (5)	5.55	5.86	+5.6%	501.00	527.52 (2)	488.48 (5)
Sep	10.63 (2,10)	9.93 (5)	10.23	10.79	+5.5%	548.05	575.75 (2)	536.79 (5)
Oct	17.83 (2,8)	16.58 (5)	17.24	18.89	+9.6%	543.71	566.28 (2)	530.11 (5)
Nov	19.19 (2)	18.04 (7)	18.50	20.05	+8.4%	492.50	510.21 (2)	479.97 (5)
Dec	23.01 (2)	21.00 (5)	22.16	24.61	+11.1%	493.05	509.82 (2)	480.14 (5)

3.5.2. Scenario B: 4.5 m × 2.6 m North Wall and 7 m × 2.6 m East Wall

Scenario B, by contrast, reconfigures the orientation; it emphasizes a broader east-facing wall and a more limited north-facing surface. This layout favors early morning ventilation but slightly reduces exhaust potential due to the smaller north window. Despite this, the scenario still performs commendably, particularly when occupant behavior is responsive. December records the highest probable NV rate, showing a 12.4% increase, the largest monthly gain across both scenarios. Overall, Scenario B shows a consistently higher behavioral impact on ventilation, with most months posting improvements around 9–12%.

Table 32 supports these findings by showing that despite Scenario B's generally lower average NV rates compared to Scenario A, the differences across configurations remain modest—averaging between 15.32 and 15.99 ACH. Configuration 3 recorded the highest average ventilation, peaking at 21.87 ACH in March, while Configuration 7 had the lowest at 15.32 ACH. Notably, ventilation performance still aligns with seasonal shifts, with peaks in warmer months and drops in May. The overall consistency across configurations suggests that while reduced wall dimensions limit airflow slightly, the effectiveness of ventilation remains strong, especially when combined with high solar gains from larger east-facing

windows, emphasizing the importance of balancing thermal comfort and ventilation needs in compact layouts.

Table 32. Natural-ventilation rates across stories, SB (Scenario B).

Configuration	Peak (ACH) (Month)	Lowest (ACH) (Month)	Average (ACH)
1	20.62 (January)	4.18 (May)	15.47
2	20.92 (January)	4.23 (May)	15.56
3	21.87 (March)	4.20 (May)	15.99
4	21.73 (March)	4.14 (May)	15.85
5	22.94 (December)	4.12 (May)	15.93
6	20.87 (January)	4.21 (May)	15.48
7	21.43 (March)	4.11 (May)	15.32
8	20.98 (January)	4.19 (May)	15.54
9	20.47 (January)	4.13 (May)	15.41
10	20.80 (January)	4.19 (May)	15.50

Under the PB model in Scenario B, occupants play a more active role in influencing ventilation outcomes. This model assumes that people respond intuitively to indoor conditions by opening windows during warmer periods or when solar exposure increases. The data shows that this behavior leads to a meaningful increase in NV across the board, with increases ranging from about 8% to over 12%. The highest behavioral impact occurs in December, with a 12.4% improvement in NV, highlighting how even layouts with limited exhaust capacity can still perform well when occupants are engaged. Notably, the consistently higher gains in Scenario B suggest that this configuration is more sensitive to user interaction, meaning thoughtful behavior can significantly offset design limitations.

As for solar gain, Scenario B consistently records higher values than Scenario A, despite its slightly less favorable orientation for NV. This is due to the expansive east-facing glazing that captures intense morning sunlight, especially during the cooler months. For instance, in December, Scenario B achieves an average solar gain of 582.15 kWh, substantially higher than Scenario A's 493.05 kWh.

Figure 12 illustrates that average monthly ventilation rates in Scenario B remain robust throughout the year, with PB consistently outperforming SB. The difference is most pronounced in cooler and transitional months—such as October and December—suggesting that adaptive occupant interaction significantly enhances natural ventilation when environmental conditions require more nuanced control. This highlights the synergistic value of combining intelligent design with realistic behavioral assumptions.

Configuration 1 frequently records the highest gains, indicating that wider, taller windows facing east are particularly influential in heat accumulation. While this can be beneficial for passive warming in winter, it poses a risk of overheating during warmer months. These findings underscore the importance of integrating adaptable shading or selective glazing into the design, particularly in east-facing zones, to ensure comfort throughout the year. Table 33 reinforces this by showing that Configuration 1 consistently produces the highest peak solar gains across almost all months, from January (564.86 kWh) to December (592.25 kWh). This repeated performance signals that its expansive glazing area captures significant solar radiation, especially during morning hours when the sun is strongest on the eastern façade. Without adequate mitigation, this can lead to thermal discomfort and increased cooling loads. Therefore, design strategies for such configurations must balance daylight access and winter heating potential with protective measures to reduce summer heat gain.

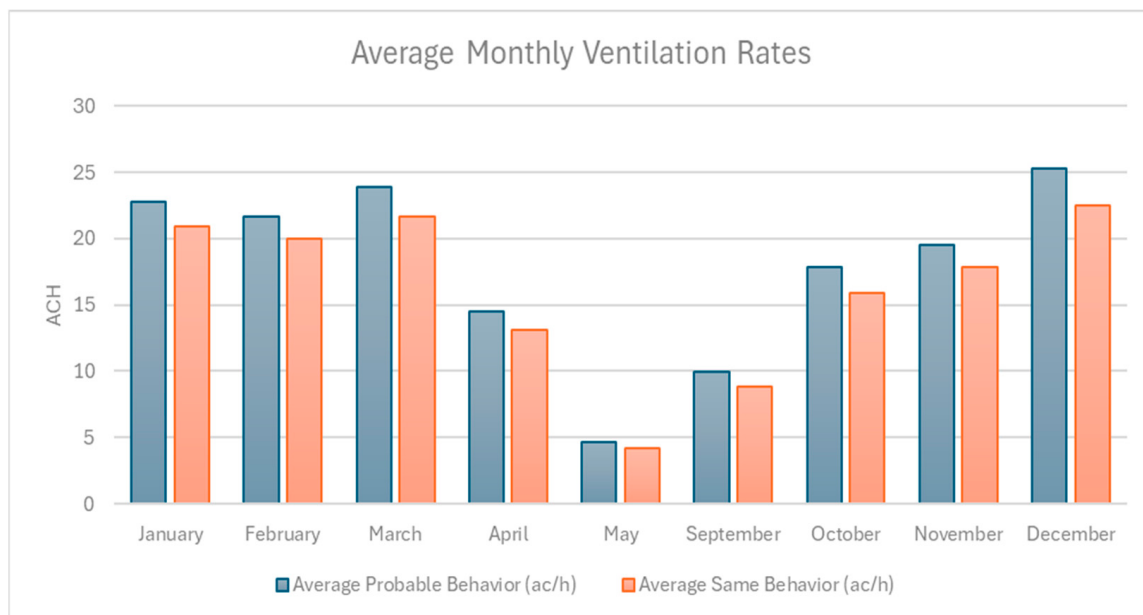


Figure 12. Story 5, Scenario B, average monthly ventilation rates (ACH), SB vs. PB.

Table 33. Ventilation and solar gain, Design Story 5, Scenario B (SB and PB).

Month	Highest NV Probable (ACH) (Config.)	Lowest NV Probable (ACH) (Config.)	Avg. NV Same (ACH)	Avg. NV Probable (ACH)	% Change	Avg. Solar Gain (kWh)	Peak Solar Gain (kWh) (Config.)	Lowest Solar Gain (kWh) (Config.)
Jan	21.32 (5)	20.34 (7)	20.89	22.80	+9.1%	555.42	564.86 (1)	548.82 (9)
Feb	20.42 (3)	19.66 (7)	20.02	21.61	+8.0%	532.91	541.37 (1)	526.73 (9)
Mar	21.87 (3)	21.43 (7)	21.70	23.91	+10.2%	552.50	559.62 (1)	546.51 (9)
Apr	13.22 (3)	12.87 (7)	13.09	14.52	+11.0%	441.47	446.34 (1)	436.76 (9)
May	4.23 (2)	4.11 (7)	4.17	4.67	+12.0%	403.35	406.77 (1)	399.15 (9)
Sep	8.92 (4)	8.67 (7)	8.83	9.92	+12.3%	509.27	516.59 (1)	504.76 (9)
Oct	16.22 (4)	15.43 (7)	15.90	17.84	+12.2%	561.58	569.92 (1)	555.23 (9)
Nov	18.09 (3)	17.55 (7)	17.81	19.53	+9.7%	564.13	573.79 (1)	557.46 (9)
Dec	22.99 (3)	22.06 (9)	22.52	25.31	+12.4%	582.15	592.25 (1)	574.96 (9)

3.5.3. Discussion: Design Implications and Behavioral Insights

In comparing both scenarios, it becomes clear that Scenario A slightly outperforms Scenario B in terms of raw ventilation potential, with a peak of 25.39 ACH versus 22.99 ACH. This advantage is attributed to the wider north-facing window acting as a superior exhaust outlet. However, Scenario B demonstrates a stronger relative response to behavioral changes, suggesting that occupant engagement, such as adjusting windows during specific times, can substantially enhance performance, even when the layout is less inherently optimal. The broader implication is that design alone does not dictate performance; the combination of window orientation, sizing, and occupant behavior collectively determines indoor comfort. Designers should consider not only optimal window configurations but also how adaptable the space is to user interaction. Moreover, to mitigate the risk of excessive solar heat gain while preserving NV, integrating passive design elements like eaves, blinds, or operable shading systems becomes essential, especially in east- and north-facing facades.

In summary, Scenario A offers stronger baseline performance in ventilation and is particularly suited for maximizing daily cross-ventilation, while Scenario B, although slightly weaker in exhaust efficiency, excels in leveraging user behavior and morning

solar exposure. Both designs benefit significantly from engaged occupants and show clear seasonal patterns that could inform adaptive strategies year-round.

3.6. Broader Applicability and Transferability

Although the specific numeric results presented here are context-dependent (Melbourne, Australia), the demonstrated relative improvements (5–12% increases in ACH from incorporating occupant behavior) and methodological insights remain valid and transferable. By utilizing the provided workflow, which integrates realistic occupant behavior into dynamic simulations, researchers and practitioners globally can achieve similarly optimized results tailored to their local conditions. For example, while in hotter climates the approach can highlight necessary shading strategies or window-operation schedules during peak solar gains, in colder climates, adaptive window configurations could optimize passive solar heating and ventilation trade-offs. Thus, the methodology and core insights have global relevance and can be widely implemented, informing both practical design guidelines and policy recommendations.

3.7. Summary and Guidelines

This study highlights that occupant behavior significantly alters window performance outcomes. Simulation results demonstrated considerable differences in ventilation rates and thermal comfort between behavior-informed scenarios and base-case assumptions. Designs that initially appeared optimal under default usage patterns often underperformed when realistic occupant behaviors were introduced. Specifically, in the context of Melbourne’s climate, north- and south-facing window designs performed best when aligned with actual occupant use patterns. Large, operable north-facing windows, as seen in Scenarios 1 and 4, enhanced ventilation potential, particularly when placement encouraged interaction. Similarly, high south-facing windows contributed to improved thermal comfort during cooler seasons without introducing excessive overheating risk. Moreover, window placement strongly influenced usability: windows positioned near the ceiling or with restricted access were less likely to be operated, regardless of their ventilation potential, indicating that usability is just as critical as physical performance. Designs with asymmetrical and mixed-orientation windows, such as in Stories 4 and 5, were particularly effective, balancing natural light and airflow while promoting more consistent use throughout the year, especially in transitional seasons. Overall, the findings underscore the necessity for early-stage design processes to integrate realistic occupant behavior models. Relying solely on default assumptions risks overestimating NV performance, whereas behavior-sensitive simulations enable more accurate predictions and support the development of human-centric, high-performing building designs. Table 34 summarizes the window design recommendations.

Table 34. Window-design recommendations.

Orientation	Window-Design Strategy	Key Parameters	Behavioral Insight	Simulation Outcome	Final Recommendation
North	Two windows (equal size)	45% WWR	Frequent opening due to glare-free daylight	High ventilation, low solar gain	✔ Recommend for daylight + ventilation
	One large central window	45% WWR, high placement	Less use due to unreachable height	Medium ventilation, better view	⚠ Only if view is priority

Table 34. Cont.

Orientation	Window-Design Strategy	Key Parameters	Behavioral Insight	Simulation Outcome	Final Recommendation
South	One large window + two side windows	Total 65% WWR	Overheating during afternoon, limited opening	High solar gain, glare issues	✗ Not ideal without shading
	Two medium windows	45% WWR	Balanced use, easy to open	Moderate ventilation and daylight	✓ Preferred for comfort
East	Large ceiling-height window	40% WWR	Low opening frequency in morning	Glare issues in early hours	⚠ Use only with shading
East	Smaller west-facing window	30% WWR	Opened more in late day	Supports cross-ventilation	✓ Good for morning–evening balance
West	One large window	40% WWR	Often kept shut due to heat	Poor thermal comfort	✗ Avoid large west-facing glass
West	Two smaller split windows	45% total WWR	More likely to be opened	Better airflow, lower overheating	✓ Recommended with shading

Overall, the guideline table is not just a set of random numbers; it is a thoughtful response in consideration of Melbourne’s climate. The dimensions are based on simulations that consider local solar angles, wind patterns, and temperature changes, ensuring that homes and buildings maximize energy efficiency and comfort throughout the year. By aligning window sizes and placements with these conditions, the guidelines create practical, climate-responsive designs that work for Melbourne’s residents (Table 35).

Table 35. Other Window-design recommendations.

Orientation	Recommended Window Dimensions	Additional Considerations
North	- Height: 2.0 m–2.4 m - Width: 1.5 m–2.0 m - Aspect ratio (H/W): >1.0 (taller than wide)	- Place operable part within 1.0–1.5 m from floor for easy access - Total WWR: 40–50% - Ideal for maximizing ventilation and daylight with minimal glare
East	- Height: 1.8 m–2.0 m - Width: 2.0 m–3.0 m - Aspect ratio: <1.0 (wider than tall)	- Use shading devices, e.g., blinds, overhangs, to control morning glare - Suitable for capturing morning light and ventilation
West	- Height: 1.5 m–1.8 m - Width: 1.5 m–2.0 m - Aspect ratio: ~1.0 (square or slightly rectangular)	- Use external shading or low-E glass to reduce afternoon heat gain - Smaller windows help manage excessive solar exposure
South	- Height: 1.8 m–2.0 m - Width: 1.8 m–2.5 m - Aspect ratio: ~1.0 (square or slightly rectangular)	- Provides consistent daylight without excessive heat gain - Suitable for spaces where glare is less of an issue

4. Limitations and Future Works

While this study provides valuable insights into optimizing window design for NV by integrating occupant behavior, several limitations should be acknowledged. First, the simulations relied on survey data from Melbourne residents, which may not fully represent behavioral patterns in other climatic or cultural contexts, potentially limiting the generalizability of the findings. Second, this study focused on a single living room

model with fixed building characteristics, which may not capture the diversity of residential building typologies or construction materials. Third, the occupant behavior models (SB and PB) were based on aggregated survey responses, which may oversimplify the complexity of individual preferences and dynamic interactions with windows, such as responses to real-time environmental feedback or socio-economic factors. Additionally, this study did not account for external factors like urban surroundings (e.g., adjacent buildings or vegetation) that could influence wind patterns and ventilation performance. Future research could address these limitations by expanding the scope to include diverse climatic zones, building types, and occupant demographics to enhance the applicability of the findings. Incorporating real-time occupant feedback through smart sensors or machine learning could refine behavior models, enabling more precise predictions of window use. Additionally, exploring hybrid ventilation systems that combine natural and mechanical strategies could provide practical solutions for challenging urban environments. Finally, integrating multi-objective optimization frameworks, such as cost–benefit analyses or life-cycle assessments, could further evaluate the trade-offs between ventilation performance, energy efficiency, and economic feasibility, supporting practical adoption by architects and builders.

5. Conclusions

This research presented a novel behavior-integrated simulation framework combining occupant behavior models (Same Behavior and Probable Behavior) derived from empirical survey data with dynamic EnergyPlus simulations to optimize window design for natural ventilation in Melbourne’s temperate residential buildings. By incorporating realistic occupant behavior, this study addresses a critical gap often overlooked in conventional simulations, enabling more accurate representation of occupant–window interactions and reducing discrepancies between predicted and actual ventilation outcomes.

Key findings include the following:

- Probable Behavior models increased ventilation rates by 5% to over 20% compared to static (Same Behavior) assumptions, demonstrating the importance of occupant variability for better predicting ventilation and indoor air quality. Static models may underestimate ventilation potential, leading to overly conservative designs.
- Moderately sized north-facing windows (around 45% WWR) combined with balanced cross-ventilation designs (e.g., north–south, east–west, north–east) consistently achieved peak ventilation rates of 25–36 ACH. These results highlight effective design strategies that optimize airflow while minimizing overheating and glare risks.
- Windows placed within occupant reach (below 1.6 m height) improved usability and increased ventilation frequency and effectiveness, emphasizing the role of ergonomic design in occupant-window operation.
- Large windows near ceilings or on west and south orientations increased solar gains (up to ~700 kWh/month), causing potential overheating and reducing window-use frequency. This reveals a trade-off between daylight benefits and thermal comfort, suggesting the need for shading or mitigation strategies in such cases.
- Balanced and symmetrical window layouts on the same façade encouraged simultaneous occupant use, enhancing overall ventilation efficiency and demonstrating the importance of coordinated window placement considering occupant behavior.

This study offers a practical occupant-sensitive design guideline matrix that helps architects and engineers make evidence-based decisions to improve real-world natural ventilation. By translating complex behavioral data into accessible guidelines, it bridges the gap between simulation insights and design practice. While developed for Melbourne’s climate, the occupant-responsive methodology is adaptable and can be applied globally by

updating climate data, occupant models, and construction standards. Policymakers may also use this framework to refine building codes and sustainability policies, aligning them with actual occupant behavior to improve building performance and comfort.

Future research should extend this occupant-integrated approach to other climates, incorporate real-time occupant feedback, and integrate adaptive shading and smart ventilation controls. These advances will foster occupant-centric building design, optimizing indoor environmental quality and energy efficiency for more responsive, sustainable buildings.

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Appendix A Configuration and Behavior Details

Design Story Details

Design Story 1: North-Facing Windows

Occupant Behavior Narrative

Occupants following this scenario frequently open and close the north-facing windows over the course of the day in response to Melbourne’s variable climate. In the morning, the windows are fully opened to let in both cool air and abundant daylight. As midday temperatures rise, occupants partially close the windows, reducing excessive heat gain. Finally, as evening approaches, the windows are adjusted once again to capture cooler air, promoting effective nighttime ventilation. This dynamic pattern of window operation underscores how the combination of a strategic north-facing window configuration and adaptive occupant behavior can enhance overall indoor comfort while minimizing reliance on mechanical cooling.

Same Behavior Pattern

- Morning (6:00 AM–10:00 AM): Fully open 100%, occupants prioritize ventilation in the morning to refresh indoor air, improve air quality, and utilize natural light.
- Midday (10:00 AM–2:00 PM): Open 50%, windows are adjusted to balance ventilation with glare and heat control.
- Afternoon (2:00 PM–6:00 PM): Open 30%, heat gain mitigation is the primary concern. Windows are limited to 30% opening to reduce thermal discomfort while still allowing for controlled ventilation.
- Evening (6:00 PM–10:00 PM): Windows are reopened to 75% to take advantage of cooler outdoor air.

Probable Behavior for wall 7 m wide × 2.6 m high.

Story	Window 1 (H × W) (m ²)	Window 2 (H × W) (m ²)	Ventilation/Lighting Impact
1	2.4 × 1.70	2.4 × 1.70	Maximizes height for daylight penetration.
Behavior pattern: Morning: Fully open to leverage horizontal daylighting and maximize fresh air intake. Midday: Open 60% to balance glare control with moderate ventilation. Afternoon: Open 30% to mitigate heat gain while retaining airflow. Evening: Open 80% to flush warm air and enhance cooling. Night: Fully closed to maintain comfort and privacy.			
2	2.2 × 1.85	2.4 × 1.85	Proportional windows enhance symmetry and light uniformity.
Behavior pattern: Morning: Fully open to enhance fresh air intake through taller windows. Midday: Open 60% to optimize balanced light diffusion and ventilation. Afternoon: Open 30% to moderate heat gain while maintaining airflow. Evening: Fully open for effective cross-ventilation and evening cooling. Night: Fully closed to maintain comfort and privacy.			
3	2.0 × 2.05	2.0 × 2.05	Balanced dimensions for airflow and daylight.
Behavior pattern: Morning: Fully open for balanced daylighting and ventilation. Midday: Open 60% to manage glare while ensuring adequate airflow. Afternoon: Open 40% to control heat with moderate ventilation. Evening: Fully open to rapidly cool the space. Night: Fully closed to maintain comfort and privacy.			
4	1.8 × 2.30	1.8 × 2.30	Wider windows for horizontal daylight spread.
Behavior pattern: Morning: Fully open to maximize horizontal daylight and fresh air. Midday: Open 70% for good light diffusion and tempered airflow. Afternoon: Open 35% to strike a balance between ventilation and reducing heat. Evening: Open 65% to remove residual warmth and improve comfort. Night: Fully closed to maintain comfort and privacy.			
5	1.5 × 2.70	1.5 × 2.70	Shorter windows reduce glare and focus on horizontal daylight spread.
Behavior pattern: Morning: Fully open to leverage horizontal daylighting and fresh morning air. Midday: Open 50% to reduce glare and maintain moderate ventilation. Afternoon: Open 20% to manage heat buildup while allowing slight airflow. Evening: Open 70% for evening cooling and horizontal airflow. Night: Fully closed to maintain comfort and privacy.			
6	1.6 × 3.4	1.6 × 1.7	Wider Window 1 prioritizes light and ventilation, while Window 2 offers flexibility for airflow during midday and afternoon.
Behavior pattern: Morning: Fully open both windows, using the wider one for increased ventilation. Midday: Window 1 open 50%, Window 2 open 70% for controlled airflow and reduced glare. Afternoon: Window 1 open 30%, Window 2 open 40% to manage heat while keeping fresh air. Evening: Fully open to maximize cross-ventilation and remove daytime heat. Night: Fully closed to maintain comfort and privacy.			

Story	Window 1 (H × W) (m ²)	Window 2 (H × W) (m ²)	Ventilation/Lighting Impact
7	1.60 × 2.05	1.6 × 3.05	Wider Window 2 enhances light spread, while Window 1 maintains airflow and complements daylighting needs.
Behavior pattern: Morning: Fully open both windows, letting the larger one flood daylight in. Midday: Window 1 open 60%, Window 2 open 40% to balance ventilation and glare. Afternoon: Window 1 open 40%, Window 2 open 25% for limited heat gain and steady airflow. Evening: Fully open both windows to cool the space effectively. Night: Fully closed to maintain comfort and privacy.			

Probable Behavior for wall 4.5 m wide × 2.6 m high.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
1	2.40 × 1.10 m ²	2.40 × 1.10 m ²	Tall windows maximize vertical daylight penetration.
Behavior pattern: Morning: Fully open to optimize vertical airflow and daylight. Midday: Open 50% to balance glare control and ventilation. Afternoon: Open 25% for moderate airflow and heat mitigation. Evening: Open 75% for improved cooling. Night: Fully closed to maintain comfort and privacy.			
2	2.0 × 1.3 m ²	2.0 × 1.3 m ²	Balanced dimensions optimize ventilation and lighting.
Behavior pattern: Morning: Fully open to balance daylight and fresh air. Midday: Open 60% for comfortable light and ventilation. Afternoon: Open 30% to manage heat while ensuring airflow. Evening: Fully open for cross-ventilation and cooling. Night: Fully closed to maintain security and comfort.			
3	1.8 × 1.45 m ²	1.8 × 1.45 m ²	Wider windows emphasize horizontal daylight spread.
Behavior pattern: Morning: Fully open to utilize horizontal daylight and airflow. Midday: Open 70% for strong ventilation and reduced glare. Afternoon: Open 40% for balanced cooling and limited heat gain. Evening: Open 80% to accelerate cooling after daytime heat. Night: Fully closed to maintain comfort and privacy.			
4	1.5 × 1.75 m ²	1.5 × 1.75 m ²	Shorter windows reduce glare and focus on horizontal daylight.
Behavior pattern: Morning: Fully open for airflow and daylight from shorter windows. Midday: Open 50% to control light spread and glare. Afternoon: Open 20% for minimal ventilation and heat management. Evening: Open 70% for effective evening cooling. Night: Fully closed to maintain comfort and privacy.			
5	2.2 × 1.20 m ²	2.2 × 1.20 m ²	Proportional windows ensure symmetrical and uniform lighting.
Behavior pattern: Morning: Fully open to maximize symmetrical light and airflow. Midday: Open 60% to balance ventilation with moderate sunlight. Afternoon: Open 25% to reduce heat gain while maintaining airflow. Evening: Fully open to enhance nighttime cooling. Night: Fully closed to maintain comfort and privacy.			

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
6	1.6 × 1.1 m ²	1.6 × 2.2 m ²	Wider window provides better light and ventilation, while Window 1 complements airflow for consistency.

Behavior pattern:
Morning: Fully open both, with the wider window favoring increased daylight.
Midday: Window 1 open 60%, Window 2 open 40% for glare control and airflow.
Afternoon: Window 1 open 40%, Window 2 open 25% to manage heat buildup.
Evening: Fully open for strong cross-ventilation and cooling.
Night: Fully closed to maintain comfort and privacy.

7	1.6 × 1.3 m ²	1.6 × 2.0 m ²	Wider Window 2 enhances horizontal daylight spread, complementing ventilation needs from Window 1.
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Behavior pattern:
Morning: Fully open both windows to start the day with fresh air.
Midday: Window 1 open 60%, Window 2 open 40% to control glare and maintain airflow.
Afternoon: Window 1 open 40%, Window 2 open 25% for heat mitigation while retaining comfort.
Evening: Fully open for effective cooling in late hours.
Night: Fully closed to maintain comfort and privacy.

Design Story 2: East–West Window Configuration
Occupant Behavior Narrative

In the morning, occupants open the east-facing window to let in natural light and warmth, gradually closing it as midday temperatures rise. In the afternoon, due to intense solar gain on the west façade, occupants carefully manage the west window, potentially opening it only slightly to introduce a cooling breeze if beneficial or relying more on shading to mitigate heat buildup. When outdoor conditions are pleasant, both windows are opened simultaneously to create a longitudinal cross-breeze, enhancing natural ventilation. Additionally, ceiling fans are occasionally used to boost air circulation, especially during periods of intense afternoon sun on the west side. This adaptive behavior ensures that indoor conditions remain comfortable while minimizing reliance on mechanical cooling systems.

Same Behavior pattern:

- Morning (6:00 AM–10:00 AM): Fully open the east-facing window to maximize early sunlight and vertical ventilation. The west-facing window is closed.
- Midday (10:00 AM–2:00 PM): The east-facing window is open 50% to balance daylight and minimize glare. The west-facing window is opened 30% to enhance cross-ventilation and reduce temperature disparities while limiting initial west sun exposure.
- Afternoon (2:00 PM–6:00 PM): The east-facing window is open 40% to reduce solar heat gain while maintaining good indirect light. The west-facing window is significantly reduced to 20% open, prioritizing blocking direct sun and heat gain based on POE findings, providing minimal cooling airflow only if outdoor conditions allow.
- Evening (6:00 PM–10:00 PM): Both windows are fully open to optimize cross-ventilation and cool the indoor space using cooler evening air.

Probable Behavior for wall 7 m wide × 2.6 m high.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
textbf1	2.4 × 3.0 m ²	2.4 × 2.3 m ²	Tall windows on both sides maximize daylight/ventilation potential. Narrower west window helps manage afternoon heat gain slightly.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: Fully open the east window for maximum daylight and vertical ventilation. West window remains closed. Midday: East window open 45% to limit glare while maintaining airflow. West window open 25% for cross-ventilation. Afternoon: East window open 35% to reduce heat gain. West window open 15% to cool the space. Evening: Fully open both windows to enhance cooling through cross-ventilation.			
2	2.2 × 3.3 m ²	2.20 × 2.50 m ²	Balanced mid-height windows ensure optimal light/ventilation distribution while addressing glare/heat gain.
Behavior pattern: Morning: Fully open the east window to prioritize airflow and early sunlight. West window remains closed. Midday: East window open 50% to balance light and ventilation. West window open 25% to maintain airflow. Afternoon: East window open 40% to reduce heat gain. West window open 20% to support cooling. Evening: Fully open both windows to promote cross-ventilation.			
3	2.0 × 3.65 m ²	2.0 × 2.75 m ²	Mid-height windows prioritize horizontal light/airflow; wider east window enhances morning potential.
Behavior pattern: Morning: Fully open the taller east-facing window to capture morning light and vertical airflow. West window remains closed. Midday: East window open 55%, minimizing glare. West window open 30% for cross-ventilation. Afternoon: East window open 40% to reduce heat gain. West window open 20% for cooling. Evening: Fully open both windows for cross-ventilation.			
4	1.8 × 4.05 m ²	1.8 × 3.05 m ²	Low-height, wide windows emphasize horizontal views/airflow; requires careful glare management when open.
Behavior pattern: Morning: Fully open the east-facing window for fresh air and daylight. West window remains closed. Midday: East window open 55%, balancing light and ventilation. West window open 35% for airflow. Afternoon: East window open 45% for controlled ventilation. West window open 25% for cooling. Evening: Fully open both windows for evening ventilation.			
5	1.6 × 4.55 m ²	1.6 × 3.40 m ²	Minimum height, wide windows maximize horizontal connection; potential for low-angle glare/overheating if managed poorly.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 60% to control glare. West window open 35% for ventilation. Afternoon: East window open 50% for ventilation. West window open 30% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
6	2.4 × 3.0 m ²	1.6 × 3.2 m ²	Tall east maximizes AM light/ventilation; low west provides distinct cross-flow path, limiting PM heat gain impact height.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 45% to control glare. West window open 35% for ventilation. Afternoon: East window open 35% for ventilation. West window open 30% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
7	2.2 × 3.3 m ²	1.8 × 3.0 m ²	Tall east window enhances AM light/airflow; lower west window balances cross-ventilation and PM heat management.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 50% to control glare. West window open 30% for ventilation. Afternoon: East window open 40% for ventilation. West window open 25% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
8	1.8 × 4.0 m ²	2.2 × 2.45 m ²	Low east window manages glare; taller west window enhances vertical light/airflow potential in PM (if desired/controlled).
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 60% to control glare. West window open 25% for ventilation. Afternoon: East window open 45% for ventilation. West window open 20% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
9	1.6 × 4.5 m ²	2.4 × 2.25 m ²	Low east window maximizes horizontal view; tall west window dominates vertical light/airflow, requires strong PM control.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 65% to control glare. West window open 20% for ventilation. Afternoon: East window open 50% for ventilation. West window open 15% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			

Probable Behavior for wall 4.5 m wide × 2.6 m high.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
1	2.4 × 1.95 m ²	1.6 × 2.15 m ²	Tall/narrow east optimizes light on small wall; low/wider west provides distinct cross-flow path, easier PM heat management.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 50% to control glare. West window open 35% for ventilation. Afternoon: East window open 40% for ventilation. West window open 25% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
2	2.2 × 2.1	1.8 × 1.95	Balanced heights/widths provide versatile ventilation and daylight spread optimized for smaller walls.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 50% to control glare. West window open 30% for ventilation. Afternoon: East window open 40% for ventilation. West window open 25% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
3	1.8 × 2.6 m ²	2.2 × 1.6 m ²	Low /wide east manages glare easily; taller/narrow west provides focused vertical airflow/light, limiting excessive PM heat gain.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 60% to control glare. West window open 25% for ventilation. Afternoon: East window open 50% for ventilation. West window open 20% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
4	1.6 × 2.9 m ²	2.4 × 1.45 m ²	Minimum height east maximizes horizontal view; tall/narrow west offers focused vertical light/ventilation, good PM heat control.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 65% to control glare. West window open 20% for ventilation. Afternoon: East window open 55% for ventilation. West window open 15% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
5	2.4 × 1.9 m ²	2.4 × 1.45 m ²	Max. height, narrow windows optimize vertical light penetration; careful PM glare/heat control needed due to height.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 45% to control glare. West window open 20% for ventilation. Afternoon: East window open 35% for ventilation. West window open 15% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
6	2.2 × 2.1 m ²	2.2 × 1.55 m ²	Mid-height windows provide balanced light/airflow; narrower west limits PM heat gain effectively.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 50% to control glare. West window open 25% for ventilation. Afternoon: East window open 40% for ventilation. West window open 20% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
7	2.0 × 2.3 m ²	2.0 × 1.7 m ²	Mid-height windows provide balanced light; wider east enhances AM potential compared to narrower west.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 55% to control glare. West window open 30% for ventilation. Afternoon: East window open 45% for ventilation. West window open 20% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
8	1.8 × 2.55 m ²	1.8 × 1.8 m ²	Low-height windows emphasize horizontal connection; balanced widths offer consistent airflow potential.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 60% to control glare. West window open 35% for ventilation. Afternoon: East window open 50% for ventilation. West window open 25% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			
9	1.6 × 2.9 m ²	1.6 × 2.1 m ²	Minimum height windows maximize horizontal view/airflow when open; wider east enhances AM light/airflow.
Behavior pattern: Morning: Fully open the east-facing window to maximize daylight. West window remains closed. Midday: East window open 65% to control glare. West window open 35% for ventilation. Afternoon: East window open 55% for ventilation. West window open 30% for cooling. Evening: Fully open both windows to optimize cross-ventilation.			

Design Story 3: South-Facing Windows

This scenario features two medium-sized south-facing windows, each with a 30% window-to-wall ratio (WWR), resulting in a combined 60% WWR. By orienting the windows to the south, the design capitalizes on consistent daylight with minimal direct solar impact, effectively reducing glare and limiting the need for artificial lighting. The moderate window size ensures a steady influx of soft, diffuse light throughout the day while minimizing overheating, making this configuration particularly suitable for maintaining comfortable indoor conditions in regions with strong afternoon sun.

Occupant Behavior Narrative

In this arrangement, occupants rely on the south-facing windows primarily for their glare-free natural light. Throughout the day, they open these windows to introduce gentle airflow and enhance indoor comfort, doing so without substantially compromising privacy or security. This measured approach to window operation strikes a balance between maintaining adequate ventilation and preventing excessive heat gain, ultimately reducing dependency on mechanical cooling and artificial lighting systems.

Same Behavior pattern:

- Morning (6:00 AM–10:00 AM): Both windows open 80% to maximize ventilation and bring in fresh air for thermal comfort.
- Midday (10:00 AM–2:00 PM): Windows partially open 40% to balance airflow, daylight penetration, and glare control.
- Afternoon (2:00 PM–6:00 PM): Windows open 30% to minimize heat gain while allowing some ventilation.
- Evening (6:00 PM–10:00 PM): Windows open 70% to cool the space and ensure adequate ventilation.
- Night (10:00 PM–6:00 AM): Fully closed windows to maintain comfort and privacy.

Probable Behavior for wall 7 m wide × 2.6 m high.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
1	1.7 × 3.2 m ²	1.7 × 3.2 m ²	The moderate height and generous width deliver a balanced daylight distribution that minimizes glare. The ample width ensures even airflow across the space, while the height limits excessive vertical solar penetration.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: Fully open both windows to maximize ventilation and natural light, avoiding early glare. Midday: Windows open 50% to manage heat gain and maintain airflow. Afternoon: Open windows 25% to control glare from the west. Evening: Open both windows 80% to improve nighttime cooling. Night: Fully closed to maintain comfort and privacy.			
2	1.8 × 3.05 m ²	1.8 × 3.05 m ²	The slightly increased height enhances vertical light diffusion into deeper parts of the room, keeping glare under control. The larger operable area also improves ventilation efficiency, supporting steady airflow throughout the day.
Behavior pattern: Morning: Open fully to maximize daylight and fresh air. Midday: Open 50% to manage indoor heat while keeping airflow consistent. Afternoon: Open both windows 30% to maintain cooling without significant heat gain. Evening: Fully open to enhance ventilation. Night: Fully closed to maintain comfort and privacy.			
3	2.0 × 2.7 m ²	2.0 × 2.7 m ²	With increased height, these windows push daylight deeper into the room's recesses while maintaining a balanced opening area for air movement. The design is ideal for spaces where diffuse, even light is key and airflow remains consistent.
Behavior pattern: Morning: Open both windows fully for maximum fresh air. Midday: Open 60% to control heat gain from sunlight. Afternoon: Open windows 20% open for reduced airflow and glare. Evening: Open fully for nighttime cooling. Night: Fully closed to maintain comfort and privacy.			
4	2.2 × 2.45 m ²	2.2 × 2.45 m ²	The taller dimensions drive strong vertical light penetration, reducing the need for artificial lighting. The moderate width still provides effective cross-ventilation, creating a design that naturally diffuses both light and air.
Behavior pattern: Morning: Fully open both windows for daylight and fresh air. Midday: Open 50% to reduce glare and indoor heat. Afternoon: Open 30% to maintain cooling. Evening: Open fully for better ventilation. Night: Fully closed to maintain comfort and privacy.			
5	2.4 × 2.25 m ²	2.4 × 2.25 m ²	Maximized height allows light to reach far into the interior, though the relatively narrower width may slightly limit airflow.
Behavior pattern: Morning: Fully open for optimal lighting and airflow. Midday: Open 50% to balance heat gain. Afternoon: Open 30% to reduce glare while maintaining cooling. Evening: Fully open to maximize ventilation. Night: Fully closed to maintain comfort and privacy.			

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
6	1.7 × 2.6 m ²	1.7 × 3.8 m ²	The dual-window approach uses the larger window to drive deep daylight penetration and robust ventilation, while the smaller window supports localized cross-breezes and glare control.
Behavior pattern: Morning: Fully open both windows. Midday: Open the larger window 50% to control glare and heat gain, open the smaller window 80% to maintain airflow. Afternoon: Open the larger window 20% to minimize heat gain from direct sunlight, open the smaller window 30% to ensure gentle airflow. Evening: Fully open both windows for cooling. Night: Fully closed to maintain comfort and privacy.			
7	1.8 m × 2.0 m ²	1.8 m × 4.0 m ²	The larger window provides the bulk of ventilation and light, reaching into all areas of the room. The smaller window tempers the intensity of direct sunlight, reducing glare. Together, they create a flexible balance between high airflow and controlled light entry.
Behavior pattern: Morning: Open both windows fully but prioritize airflow through the larger window to reach all areas of the room. Midday: Open the larger window 60% to control glare and heat, open the smaller window 70% to allow continuous ventilation. Afternoon: Open the larger window 30% to manage glare and overheating, and keep the smaller window 40% open for consistent airflow. Evening: Open the larger window fully to cool down the space and the smaller window 60% open for balanced air exchange. Night: Fully closed to maintain comfort and privacy.			
8	2.0 m × 2.15 m ²	2.0 m × 3.3 m ²	The larger window is designed to harvest daylight and maximize airflow, while the smaller window acts as a regulating element that limits direct solar exposure, ensuring that heat gain and glare remain under control.
Behavior pattern: Morning: Fully open both windows to provide significant ventilation. Midday: Open the larger window 70% to manage indoor heat while opening the smaller window 50% for steady airflow. Afternoon: Open larger window 90% to control glare and overheating and open smaller window 30% for gentle cooling. Evening: Open both windows fully for nighttime cooling. Night: Fully closed to maintain comfort and privacy.			
Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
9	2.2 × 1.7 m ²	2.2 × 3.3 m ²	The larger window dominates in delivering natural light and ventilation, with the smaller window offering a refined control for glare and localized airflow. This pairing supports both effective cooling and light diffusion.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: Open both windows fully to maximize daylight and ventilation. Midday: Open the larger window 50% to manage heat gain, open the smaller window 70% for ventilation. Afternoon: Open larger window 20%, open smaller window 50% to balance airflow and glare. Evening: Open both windows fully for nighttime cooling. Night: Fully closed to maintain comfort and privacy.			
10	2.4 × 1.8 m ²	2.4 × 2.75 m ²	Taller overall dimensions mean that the larger window floods the interior with natural light and the smaller window complements this by moderating the influx of direct sunlight.
Behavior pattern: Morning: Fully open both windows, taking advantage of the taller height for effective airflow and lighting. Midday: Open the larger window 60% to limit heat gain, open the smaller window 50% for airflow. Afternoon: Open the larger window 30%, open the smaller window 40% open for balanced airflow. Evening: Open both windows fully for night cooling. Night: Fully closed to maintain comfort and privacy.			
1	2.0 × 1.75 m ²	2.0 × 1.75 m ²	Equal dimensions ensure that daylight and airflow are evenly distributed.
Behavior pattern: Morning: Fully open both windows for airflow and daylight. Midday: Open 50% to manage glare and airflow. Afternoon: Open 30% for controlled heat gain. Evening: Open 70% to cool the space. Night: Fully closed to maintain comfort and privacy.			
2	1.8 × 1.95 m ²	1.8 × 1.95 m ²	Although slightly shorter, these windows still support good natural light penetration and effective air exchange.
Behavior pattern: Morning: Fully open for maximum ventilation. Midday: Open 40% to balance glare and airflow. Afternoon: Open 20% to limit heat gain. Evening: Open 60% for effective cooling. Night: Fully closed to maintain comfort and privacy.			
3	1.75 × 2.0 m ²	1.75 × 2.0 m ²	Optimized to control excessive glare, the dimensions allow moderate but effective ventilation.
Behavior pattern: Morning: Open 70% for airflow and light. Midday: Open 30% to reduce glare. Afternoon: Open 20% for controlled ventilation. Evening: Open 60% to cool the space. Night: Fully closed to maintain comfort and privacy.			
4	2.4 × 1.45 m ²	2.4 × 1.45 m ²	Emphasizing vertical light entry, these tall windows deliver light deep into the space while their narrow width naturally limits the volume of air exchanged.

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: Fully open to maximize ventilation and light. Midday: Open 50% to balance airflow and light. Afternoon: Open 30% to reduce heat gain. Evening: Open 70% for cooling. Night: Fully closed to maintain comfort and privacy.			
5	2.0 × 1.15 m ²	2.0 × 2.3 m ²	The wider window offers robust ventilation and abundant natural light, while the narrower one serves to control direct solar penetration and glare.
Behavior pattern: Morning: Fully open both windows for airflow. Midday: Open wider window 50% and narrower window 30% to balance airflow and light. Afternoon: Close wider window, open narrower window 20%. Evening: Open both 70% for cooling. Night: Fully closed to maintain comfort and privacy.			
6	1.8 × 1.3 m ²	1.8 × 2.6 m ²	The larger window is the primary source of light and airflow, whereas the smaller window fine-tunes the interior environment by reducing excessive brightness and managing heat gain.
Behavior pattern: Morning: Fully open both windows. Midday: Open larger window 50% and smaller window 30%. Afternoon: Close larger window, open smaller window 20%. Evening: Open both 70% for night cooling. Night: Fully closed to maintain comfort and privacy.			
7	2.4 m × 1.0 m ²	2.4 m × 2.0 m ²	The tall design encourages deep vertical light diffusion. The smaller window provides additional control, ensuring that high-intensity sunlight does not lead to overheating or glare.
Behavior pattern: Morning: Fully open both windows. Midday: Open larger window 60%, open smaller smaller 40%. Afternoon: Open smaller window 30%, close larger window. Evening: Open both 70% for night cooling. Night: Fully closed to maintain comfort and privacy.			
8	1.7 × 1.35 m ²	1.7 × 2.7 m ²	This combination focuses on horizontal airflow while still allowing sufficient natural light.
Behavior pattern: Morning: Fully open both windows. Midday: Open larger window 50% and smaller window 30%. Afternoon: Close larger window, open smaller window 20%. Evening: Open both 60% for night cooling. Night: Fully closed to maintain comfort and privacy.			

Story	Window 1 (H × W)	Window 2 (H × W)	Ventilation/Lighting Impact
9	2.0 × 1.4 m ²	2.0 × 2.1 m ²	Both windows work in tandem to ensure a balanced mix of daylight and ventilation.
Behavior pattern: Morning: Fully open both windows. Midday: Open wider window 50%, open smaller window 30%. Afternoon: Open narrower window 20%, close wider window. Evening: Open both 70% for night cooling time. Night: Fully closed to maintain comfort and privacy.			
10	1.7 × 1.65 m ²	1.7 × 2.4 m ²	The dimensions ensure that even with limited vertical reach, the room remains properly ventilated through carefully managed opening strategies.
Behavior pattern: Morning: Fully open both windows. Midday: Open larger window 40%, open smaller window 30%. Afternoon: Close larger window, open smaller window 20%. Evening: Open both windows 60%. Night: Fully closed to maintain comfort and privacy.			

Design Scenario Four

North–South Window Configuration
Occupant Behavior Narrative

In colder seasons, occupants primarily leverage the north-facing windows to bring in fresh air and harness passive solar gain. When needed, they adjust blinds or shading devices to manage heat buildup or glare, preserving a comfortable indoor environment. As outdoor temperatures increase, residents open both the north and south windows to generate a strong cross-ventilation flow. The larger south window naturally draws out warm air, creating a cooler, more comfortable interior. Through this thoughtful use of operable windows and targeted shading, occupants minimize reliance on mechanical cooling and artificial lighting, maintaining a healthy balance between energy efficiency and indoor comfort.

Same Behavioral pattern:
Morning (6:00 AM–10:00 AM):
North windows: Fully open to maximize cross-ventilation and bring in fresh air.
South window: Fully open to enhance air exchange and allow diffuse morning light.
Midday (10:00 AM–2:00 PM):
North windows: Open 40% to allow controlled airflow while minimizing glare.
South window: Open 30% to balance indirect light and heat control.
Afternoon (2:00 PM–6:00 PM):
North windows: Open 20% to maintain minimal airflow.
South window: Closed to block direct sunlight and reduce heat gain.
Evening (6:00 PM–10:00 PM):
North windows: Open wider 70% for steady ventilation and cooling.
South window: Open wider 60% to act as an exhaust for warm air and allow evening breezes.
Night (10:00 PM–6:00 AM):
Both fully close for thermal stability and security.

Probable Behavior for wall 7 m wide × 2.6 m high.

Story	2 × Window North (H × W)	Window South (H × W)	Ventilation/Lighting Impact
1	2.4 × 2.0 m ²	2.4 × 3.0 m ²	Balanced north windows ensure consistent ventilation, while the tall south window enhances vertical daylight penetration, minimizing reliance on artificial lighting.
Behavior pattern: Morning: Fully open all windows to maximize ventilation and bring in fresh air. Midday: Open 50% to balance glare control and airflow. Afternoon: Open 30% to limit solar heat gain while maintaining ventilation. Evening: Open windows 70% to cool the space. Night: Fully closed to maintain comfort and privacy.			
2	2.2 × 2.0 m ²	2.2 × 3.3 m ²	Slightly shorter south window balances light penetration and glare control. North windows ensure cross-ventilation for thermal comfort.
Behavior pattern: Morning: Fully open all windows for maximum ventilation. Midday: Open south window to 50% and north windows to 40% to control glare. Afternoon: Slightly open north windows 30% and keep the south window closed. Evening: Open all windows 70% for cooling. Night: Fully closed to maintain comfort and privacy.			
3	2.0 × 2.3 m ²	2.0 × 3.6 m ²	Larger north windows emphasize airflow, while the taller south window focuses on warm air exhaust and vertical daylight.
Behavior pattern: Morning: Fully open all windows to improve ventilation. Midday: Open north windows 50% and the south window 30% to balance light and airflow. Afternoon: Slightly open the north windows 20% and keep the south window closed. Evening: Open all windows to 70% for effective cooling. Night: Fully closed to maintain comfort and privacy.			
4	1.8 × 2.60 m ²	1.8 × 4.0 m ²	Compact north windows minimize glare, while the large south window ensures consistent ventilation and daylight penetration.
Behavior pattern: Morning: Fully open all windows for maximum airflow. Midday: Open north windows 50% and the south window 30% to control glare. Afternoon: Slightly open 20% north windows while keeping the south window closed. Evening: Open all windows 70% for nighttime cooling. Night: Fully closed to maintain comfort and privacy.			
5	1.6 × 2.80 m ²	1.6 × 4.60 m ²	Narrow north windows prioritize glare control, while the large south window enhances thermal comfort and daylight distribution.

Story	2 × Window North (H × W)	Window South (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: Fully open all windows for cross-ventilation. Midday: Open north windows 50% and south window 30% to minimize glare and control heat. Afternoon: Keep the south window closed and north windows slightly open 20%. Evening: Open all windows 70% for effective cooling. Night: Fully closed to maintain comfort and privacy.			
6	1.6 × 2.90 m ²	2.2 × 3.3 m ²	Shorter north windows reduce solar heat gain and glare, providing steady cross-ventilation. The taller south window enhances daylight penetration deeper into the room, supporting passive cooling and indirect light.
Behavior pattern: Morning: Fully open all windows to promote cross-ventilation and fresh air. Midday: Open north and south window 50% to balance airflow and light. Afternoon: Open north windows 30% and keep the south window closed to reduce solar heat gain. Evening: Open all windows 80% to cool the space naturally. Night: Fully closed to maintain comfort and privacy.			
7	1.7 × 2.7 m ²	2.4 × 3.0 m ²	Balanced dimensions on the north side ensure consistent airflow and daylight. The taller south window maximizes vertical daylight penetration and facilitates heat exhaust.
Behavior pattern: Morning: Fully open all windows for ventilation and fresh air. Midday: Open north windows 50% and south window 30% to maintain thermal comfort. Afternoon: Open north windows 30% and keep the south window mostly closed. Evening: Open all windows 70% for nighttime cooling. Night: Fully closed to maintain comfort and privacy.			
8	1.80 × 2.60 m ²	2.2 × 3.3 m ²	Taller north windows prioritize ventilation, allowing for improved airflow. The south window enhances daylighting and heat removal, supporting effective passive cooling.
Behavior pattern: Morning: Fully open all windows for cross-ventilation. Midday: Open north windows 50% and south window 40% to balance airflow and light control. Afternoon: South window closed, and open the north windows 30%. Evening: Open all windows to 80% for natural cooling. Night: Fully closed to maintain comfort and privacy.			
9	1.6 × 2.90 m ²	2.4 × 3.0 m ²	Compact north windows provide controlled ventilation and reduce glare. The larger south window supports deep daylight penetration and passive cooling.
Behavior pattern: Morning: Fully open all windows for fresh air and ventilation. Midday: Open north windows 50% and south window 40% to balance light and airflow. Afternoon: Open north windows 20% while keeping the south window closed. Evening: Open all windows 70% for cooling. Night: Fully closed to maintain comfort and privacy.			

Story	2 × Window North (H × W)	Window South (H × W)	Ventilation/Lighting Impact
10	1.7 × 2.6 m ²	2.2 × 3.3 m ²	Proportional heights focus on effective airflow through the north windows. The south window prioritizes passive lighting and enhances natural ventilation. Optimized for spaces requiring steady cross-ventilation and strong passive cooling.

Behavior pattern:

Morning: Fully open all windows for cross-ventilation and daylight.

Midday: Open north windows 50% and south window 30% to manage light and airflow.

Afternoon: Slightly open north windows 20% while keeping the south window closed.

Evening: Open all windows to 70% for natural cooling.

Night: Fully closed to maintain comfort and privacy.

Probable Behavior for wall 4.5 m wide × 2.6 m high.

Story	2 x Window North (H × W)	Window South (H × W)	Ventilation/Lighting Impact
1	2.4 × 1.2 m ²	2.4 × 1.9 m ²	Balanced dimensions provide consistent ventilation and indirect light. The south window enhances vertical daylight penetration.

Behavior pattern:

Morning: Fully open all windows to allow fresh air and vertical ventilation.

Midday: Open all windows 50% to balance light and airflow.

Afternoon: Open 30% north windows and keep the south window closed.

Evening: Open all windows 70% for cooling.

Night: Fully closed to maintain comfort and privacy.

2	2.2 × 1.4 m ²	2.2 × 3.3 m ²	Slightly shorter south window balances light penetration and glare control. North windows ensure cross-ventilation for thermal comfort. Adapted dimensions prioritize glare-free light.
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Behavior pattern:

Morning: Fully open all windows for ventilation.

Midday: Open north windows 50% and the south window 40% for light and airflow.

Afternoon: Keep the north windows slightly open 20% and close the south window.

Evening: Open all windows 70% for cooling.

Night: Fully closed to maintain comfort and privacy.

3	2.2 × 1.4 m ²	2.0 × 2.40 m ²	South window reduces glare and enhances ventilation. Larger north windows maintain effective cross-ventilation.
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Behavior pattern:

Morning: Fully open all windows for fresh air exchange.

Midday: Partially open north windows 40% and south window 30%.

Afternoon: Slightly open 20% the north windows; keep the south window closed.

Evening: Open all windows 70% for nighttime cooling.

Night: Fully closed to maintain comfort and privacy.

Story	2 x Window North (H × W)	Window South (H × W)	Ventilation/Lighting Impact
4	1.8 × 1.60 m ²	1.8 × 2.60 m ²	Narrow north windows minimize solar gain, while the larger south window ensures indirect light and heat exhaust.
Behavior pattern: Morning: Fully open all windows for cross-ventilation. Midday: Open smaller north windows 40% and south window 50% for light and airflow. Afternoon: Close the south window and keep the north windows open 20%. Evening: Open all windows 70% for effective nighttime cooling. Night: Fully closed to maintain comfort and privacy.			
5	1.6 × 1.80 m ²	1.6 × 2.90 m ²	Narrow north windows reduce glare, while the tall south window focuses on indirect light and ventilation.
Behavior pattern: Morning: Fully open all windows for ventilation and daylight. Midday: Open north windows 50% and south window 30% to balance heat and light. Afternoon: Keep the north windows slightly open 20%; close the south window. Evening: Open all windows 70% for cooling. Night: Fully closed to maintain comfort and privacy.			
6	1.6 × 1.8 m ²	2.2 × 2.0 m ²	Shorter north windows reduce solar heat gain and glare, providing steady cross-ventilation. The taller south window enhances daylight.
Behavior pattern: Morning: Fully open all windows 100% to allow fresh air and maximize ventilation. Midday: Open north windows 50% and south window 40% to balance airflow and light control. Afternoon: Open north windows 20% and keep the south window closed to reduce solar heat gain. Evening: Open all windows 80% to cool the room naturally. Night: Fully closed to maintain comfort and privacy.			
7	1.7 × 1.7 m ²	2.4 × 2.0 m ²	Balanced dimensions on the north wall ensure consistent airflow. The taller south window provides deep vertical daylight penetration and supports heat exhaust.
Behavior pattern: Morning: Fully open all windows for cross-ventilation and fresh air. Midday: Open north windows 50% and south window 40% to manage glare and thermal comfort. Afternoon: Slightly open north windows 30% and keep the south window closed. Evening: Open all windows 70% for natural cooling. Night: Fully closed to maintain comfort and privacy.			
8	1.80 × 1.7 m ²	2.2 × 2.10 m ²	Taller north windows prioritize airflow and ventilation efficiency. The south window enhances daylighting and supports passive cooling.

Story	2 x Window North (H × W)	Window South (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: Fully open all windows for ventilation. Midday: Open north windows 50% and south window 40% to balance light and airflow. Afternoon: Keep the south window closed and open the north windows slightly 20%. Evening: Open all windows to 80% for nighttime cooling. Night: Fully closed to maintain comfort and privacy.			
9	1.60 × 1.80 m ²	2.4 × 2.0 m ²	Compact north windows focus on glare control and steady ventilation. The larger south window provides strong daylight penetration and efficient heat exhaust.
Behavior pattern: Morning: Fully open all windows for fresh air and ventilation. Midday: Open north windows 50% and south window 30% to balance heat and light control. Afternoon: Slightly open north windows 20% while keeping the south window closed. Evening: Open all windows to 80% for effective cooling. Night: Fully closed to maintain comfort and privacy.			
10	1.7 × 1.7 m ²	2.2 × 2.2 m ²	Proportional heights focus on optimized cross-ventilation through the north windows.
Behavior pattern: Morning: Fully open all windows for cross-ventilation and daylight. Midday: Open north windows 50% and south window 30% to manage light and airflow. Afternoon: Open north windows 20%, keeping the south window closed. Evening: Open all windows 70% for nighttime cooling. Night: Fully closed to maintain comfort and privacy.			

Design Story 5: North—East Windows
Occupant Behavior Narrative

In colder seasons, occupants primarily leverage the north-facing window to bring in fresh air and harness passive solar gain when available. When needed, they adjust blinds or shading devices to manage heat buildup or glare, preserving a comfortable indoor environment.

As outdoor temperatures increase, residents open both the north and east windows to generate a strong cross-ventilation flow. The larger north window naturally draws out warm air, particularly in the afternoon and evening when paired with the east windows, creating a cooler, more comfortable interior. Through this thoughtful use of operable windows and targeted shading, occupants minimize reliance on mechanical cooling and artificial lighting, maintaining a healthy balance between energy efficiency and indoor comfort.

Same Behavioral pattern:

- Morning (6:00 AM–10:00 AM): Open east 80%, open north 40%. Most fresh air enters from east side, with some cross-flow exiting north.
- Midday (10:00 AM–2:00 PM): East 30%, north 50%.
- Afternoon (2:00 PM–6:00 PM): East 20%, north 60%.
- Evening (6:00 PM–10:00 PM): East 70%, north 70%.
- Night (10:00 PM–6:00 AM): Both fully closed.

Probable Behavior for wall 7 m wide $\times$ 2.6 m high.

Story	Window North (H $\times$ W)	East Windows (Each): (H $\times$ W)	Ventilation/Lighting Impact
1	2.4 $\times$ 3.05 m ²	2.4 $\times$ 1.20 m ²	The east windows provide bright morning light beneficial for occupant alertness. The north window balances daylight later in the day, minimizing harsh direct sun and glare.
Behavior pattern: Morning: East windows 100% open, north window 50% open. Midday: East windows 30% open (reduce glare), north window 50% open. Afternoon: East windows 20% open, north window 70% open. Evening: East windows 70% open, north window 70% open. Night: Fully closed to maintain comfort and privacy.			
2	2.2 $\times$ 3.30 m ²	2.2 $\times$ 1.35 m ²	Morning sun from the east is strong but can be controlled via partial opening or blinds. The taller north window distributes soft daylight deeper into the room throughout midday/afternoon.
Behavior pattern: Morning: East 80% open, north 50% open. Midday: East 40% open, north 50% open. Afternoon: East 20% open, north 60% open. Evening: East 70% open, north 70% open. Night: Fully closed to maintain comfort and privacy.			
3	2.0 $\times$ 3.65 m ²	2.0 $\times$ 1.45 m ²	East windows are moderately tall for morning sunlight; the vertical north window yields stable daytime illumination, reducing reliance on electric lighting.
Behavior pattern: Morning: East 90% open, north 40% open. Midday: East 30% open, north 60% open. Afternoon: East 20% open, north 70% open. Evening: East 80% open, north 80% open. Night: Fully closed to maintain comfort and privacy.			
4	1.8 $\times$ 4.05 m ²	1.8 $\times$ 1.65 m ²	Provides strong vertical air circulation potential. Extended vertical glazing helps light reach deeper. Morning sun from the east can be intense.
Behavior pattern: Morning: East 80% open, north 30% open. Midday: East 30% open, north 50% open. Afternoon: East 20% open, north 70% open. Evening: East 60% open, north 60% open. Night: Fully closed to maintain comfort and privacy.			
5	1.6 $\times$ 4.55 m ²	1.6 $\times$ 1.85 m ²	Despite narrower widths, the tall dimension still allows a good vertical spread of daylight. East windows provide strong morning illumination.

Story	Window North (H × W)	East Windows (Each): (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: East 100% open, north 40% open. Midday: East 40% open, north 50% open. Afternoon: East 20% open, north 70% open. Evening: East 80% open, north 80% open. Night: Fully closed to maintain comfort and privacy.			
6	2.2 × 3.30 m ²	1.6 × 1.85 m ²	Good morning sun from narrower but tall east openings; stable diffuse light from north reduces midday glare.
Behavior pattern: Morning: East ~90% open, north 60% open. Midday: East 20% open, north 50% open. Afternoon: East 20% open, north 70% open. Evening: East 70% open, north 70% open. Night: Fully closed to maintain comfort and privacy.			
7	2.4 × 3.05 m ²	1.7 × 1.70 m ²	East squares provide robust morning brightness; the wide north window ensures consistent light for the rest of the day.
Behavior pattern: Morning: East 100% open, north 50% open. Midday: East 40% open, north 60% open. Afternoon: East 20% open, north 70% open. Evening: East 70% open, north 70% open. Night: Fully closed to maintain comfort and privacy.			
8	2.2 × 3.30 m ²	1.8 × 1.65 m ²	Creates a balanced approach: neither too tall nor too wide. East façade supplies ample morning daylight; the north façade offers an even glow all day.
Behavior pattern: Morning: East 80% open, north 60% open. Midday: East 30% open, north 50% open. Afternoon: East 20% open, north 70% open. Evening: East 80% open, north 80% open. Night: Fully closed to maintain comfort and privacy.			
9	2.4 × 3.03 m ²	1.6 × 1.85 m ²	East windows give solid morning light; the wide north window ensures good illumination across midday/afternoon.
Behavior pattern: Morning: East 90% open, north 40% open. Midday: East 30% open, north 60% open. Afternoon: East 20% open, north 70% open. Evening: East 70% open, north 70% open. Fully closed to maintain comfort and privacy.			

Story	Window North (H × W)	East Windows (Each): (H × W)	Ventilation/Lighting Impact
10	2.2 × 3.30 m ²	1.7 × 1.70 m ²	Morning cross-vent can be strong if all are opened wide. East squares let in direct morning light while the north window stabilizes interior illumination through midday.

Behavior Pattern:

Morning: East 100% open, north 50% open.

Midday: East 40% open, north 50% open.

Afternoon: East 20% open, north 70% open.

Evening: East 80% open, north 80% open.

Night: Fully closed to maintain comfort and privacy.

Probable Behavior for wall 4.5 m wide × 2.6 m high.

Story	Window North (H × W)	East Windows (each): (H × W)	Ventilation/Lighting Impact
1	2.4 × 1.95 m ²	2.4 × 1.90 m ²	The north window offers more diffuse daytime light, reducing glare issues midday/afternoon.

Behavior pattern:

Morning: East 100% open, north 50% open.

Midday: East 40% open, north 50% open.

Afternoon: East 30% open, north 60% open.

Evening: East 70% open, north 70% open.

Night: Fully closed to maintain comfort and privacy.

2	2.2 × 2.15 m ²	2.2 × 2.05 m ²	A tall north window plus two moderately sized east window deliver cross-vent potential in the morning and evening. East windows supply robust morning sun, the north window ensures stable daylight.
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Behavior pattern:

Morning: East 80% open, north 40% open.

Midday: East 30% open, north 50% open.

Afternoon: East 20% open, north 60% open.

Evening: East 70% open, north 70% open.

Night: Fully closed to maintain comfort and privacy.

3	2.0 × 2.35 m ²	2.0 × 2.30 m ²	North window pairs with fairly tall east windows for a balanced cross-vent. The tall east windows deliver strong early light.
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Behavior pattern:

Morning: East 90% open, north 40% open.

Midday: East 30% open, north 60% open.

Afternoon: East 20% open, north 70% open.

Evening: East 80% open, north 80% open.

Night: Fully closed to maintain comfort and privacy.

4	1.8 × 2.60 m ²	1.8 × 2.55 m ²	A taller north window and two tall/wide east windows allows a significant vertical airflow path. East windows produce intense morning light.
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Story	Window North (H × W)	East Windows (each): (H × W)	Ventilation/Lighting Impact
Behavior pattern: Morning: East 100% open, north 50% open. Midday: East 40% open, north 50% open. Afternoon: East 20% open, north 70% open. Evening: East 70% open, north 70% open. Night: Fully closed to maintain comfort and privacy.			
5	1.6 × 2.95 m ²	1.6 × 2.85 m ²	Narrower tall dimension brings decent morning sun from the east and stable midday brightness from the north.
Behavior pattern: Morning: East 90% open, north 40% open. Midday: East 30% open, north 60% open. Afternoon: East 20% open, north 70% open. Evening: East 80% open, north 80% open. Night: Fully closed to maintain comfort and privacy.			
6	2.2 × 2.15 m ²	1.6 × 2.85 m ²	Occupants achieve a strong breeze with two large east sashes plus one moderate north sash.
Behavior pattern: Morning: East 80% open, north 40% open. Midday: East 20% open, north 50% open. Afternoon: East 20% open, north 70% open. Evening: East 70% open, north 70% open. Night: Fully closed to maintain comfort and privacy.			
7	2.4 × 1.95 m ²	1.7 × 2.65 m ²	A wide north window plus two tall east windows foster strong cross-vent if opened simultaneously. Lighting: East windows supply bright morning light; wide north window helps fill the space with more diffuse brightness midday onward.
Behavior pattern: Morning: East 100% open, north 50% open. Midday: East 40% open, north 50% open. Afternoon: East 20% open, north 60% open. Evening: East 70% open, north 70% open. Night: Fully closed to maintain comfort and privacy.			
8	2.2 × 2.15 m ²	1.8 × 2.55 m ²	Can quickly exchange air in morning/evening. East side can be bright early. North side remains easy on the eyes throughout the day.
Behavior pattern: Morning: East 90% open, north 40% open. Midday: East 30% open, north 60% open. Afternoon: East 20% open, north 70% open. Evening: East 80% open, north 80% open. Night: Fully closed to maintain comfort and privacy.			

Story	Window North (H × W)	East Windows (each): (H × W)	Ventilation/Lighting Impact
9	2.4 × 1.95 m ²	1.6 × 2.85 m ²	Open them wide in morning/evening for a big flush of air. The east windows let in strong morning sun, the wide north window illuminates midday/afternoon zones without direct glare.
Behavior pattern: Morning: East 100% open, north 50% open. Midday: East 40% open, north 50% open. Afternoon: East 20% open, north 70% open. Evening: East 70% open, north 70% open. Night: Fully closed to maintain comfort and privacy.			
10	2.2 × 2.15 m ²	1.7 × 2.65 m ²	Good synergy for cross-flow ventilation. East orientation is strong in the morning; the north window stays helpful for less direct, glare-free light midday.
Behavior pattern: Morning: East 90% open, north 40% open. Midday: East 30% open, north 50% open. Afternoon: East 20% open, north 60% open. Evening: East 80% open, north 80% open. Night: Fully closed to maintain comfort and privacy.			

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