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Research Article

Adjusting Building Renovation Design to Occupant Characteristics

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Abstract (250 words) Style Name [Abstract, Keywords Aptos, 10, Bold]

This study highlights the importance of integrating the occupants' schedule into the building renovation design process, as it directly impacts the building's future energy consumption. To this end, the research examined operational energy consumption in three buildings inhabited by three distinct population groups: families, hotel employees, and students. Simulations conducted in the study reveal how the occupants' schedule affects operational energy consumption. Computer models were utilized to analyze building behavior under varying climatic conditions throughout the year. The simulations evaluated parameters such as wall-to-window ratio (WWR), building orientation, glazing type, thermal insulation thickness and type. The findings indicate that factors like WWR and orientation significantly impact energy consumption, but the effect varies across population groups. For instance, occupants who spend extended hours in the building during peak heat hours, such as students, benefit more from enhanced thermal insulation and external shading compared to families who are often absent during these hours. The study's findings underscore the importance of integrating occupant characteristics into the building renovation design process, combining precise data analysis, alternative evaluations, and project-specific adaptations.

Keywords: Operational energy; Building renovation; Occupant characteristics; Energy simulation

Highlights

- The importance of integrating the occupants' schedule into the building renovation design process is assessed.
- Simulations conducted in the study reveal how the occupants' schedule affects operational energy consumption.
- Findings indicate that the impact on energy consumption of factors like WWR and orientation varies across occupants.

1 Introduction

Renovating existing buildings in hot, dry regions is one of the few short/medium term solutions that can facilitate significant reductions in operational electricity consumptions at scale, while improving thermal resilience. The challenge is not only to enhance envelope performance and façade control but to do so in a way that aligns with the temporal patterns of occupancy that occur in practice. When renovation packages are designed around generalized building archetypes, the resulting prediction–measurement gap tends to widen, especially in cooling dominated contexts where the coincidence of presence, gains and outdoor conditions is decisive.

Several previous studies have examined the human side of building energy. Reviews have underscored that schedule realism and behavior representation are primary determinants of performance, not secondary refinements. Studies such as Hong et al. (2017) and Yan et al. (2015) propose frameworks for representing presence, adaptive comfort actions and device use in simulation. D'Oca et al. (2018) integrate empirical and modelling evidence to motivate occupant-centric design workflows, while Gunay et al. (2016) discuss control-oriented models that link behavior with HVAC and lighting controls. These studies lead to a clear conclusion: operational outcomes are best predicted when occupant heterogeneity and schedule variability are modelled explicitly.

Methodologically, several research approaches have been developed in parallel. Behavioral models of window operation, equipment use, and lighting switching have moved from static assumptions to stochastic formulations, often Markov or logistic regression based, which better reproduce observed diversity (e.g., Reinhart & Wienold, 2011; Chen et al., 2017). Urban scale frameworks incorporate such models to propagate uncertainty across many buildings (Carlucci et al., 2021; Virote & Neves-Silva, 2012; Lim & Zhai, 2017). Accuracy studies have highlighted that even small misspecifications of setpoints or gains can lead to large prediction errors (Stein & Meier, 2000), underlining the importance of schedule selection in cooling-dominated climates. On the comfort side, adaptive models based on empirical evidence (de Dear & Brager, 1998) and more recent personal comfort models (Kim et al., 2018) expand plausible setpoint strategies and thus the space of design options.

Standards provide the basis for compliance and benchmarking. ASHRAE 90.1 codifies envelope, system and lighting prescriptions for various uses, while ASHRAE 55 formalizes thermal environmental conditions that inform setpoint choices. Israeli Standard 5282 (Part 2) supplies national reference assumptions and rating procedures for non-residential buildings. Yet all three, by necessity, simplify schedules and internal gains to remain broadly applicable. Differences in these simplifications can dominate cross-standard comparisons; for example, typical lighting and plug-load intensities in ASHRAE archetypes are substantially higher than in Israeli assumptions. When occupant sensitive schedules derived from local evidence are used, outcomes can depart from both sets of archetypes in systematic ways.

The present study investigates three buildings that host families, hotel employees and students. The research question asks how façade orientation, WWR, glazing specification and insulation thickness interact with the distinct daily rhythms of these types of building occupants to shape annual cooling electricity and peak sensible loads. The contribution is to translate occupant-centric insights into renovation guidance that is specific to user groups and therefore more likely to deliver promised savings in operation.

2 Research Objectives

Cooling demand in a space is shaped by an energy balance over time that aggregates conductive transfer through opaque assemblies, solar and long wave gains through glazing, internal gains from people and devices and latent/sensible loads associated with ventilation and infiltration. The envelope-related terms scale with thermal resistances and areas and are modulated by indoor/outdoor temperature differences and solar irradiance. The occupant-related terms scale with presence, metabolic rates and device use. Because these drivers interact multiplicatively with the hourly schedule, two building envelopes that are identical in aggregate can yield different annual outcomes when the timing of presence differs.

Glazing area and properties affect cooling demand through conductive and radiative pathways. Increasing window fraction on east and west façades raises afternoon gains in hot and dry climates; lowering the solar heat gain coefficient or introducing external shading dampens those gains. Insulation thickness reduces conductive loads through opaque assemblies but exhibits diminishing returns as thermal resistance increases; after a threshold, residual loads are dominated by gains through glazing and by internal loads, so further investment in opaque envelopes produces smaller increments of savings. Orientation interacts with both wall-to-window ratio (WWR) and occupancy schedules by exposing different façades to peak sun at different times of day.

These relations motivate the simulation design in this research: since the goal is to prioritize measures that most influence cooling electricity for each type of building occupant, the analysis must vary orientation and glazing while also changing insulation levels to assess diminishing returns. The results can thus be expressed relative to occupant schedules, not in isolation.

Accordingly, the goal of this research is to reduce operational electricity without undermining comfort by tailoring renovation design to distinct occupant groups. The analysis focuses on identifying which envelope and façade parameters matter most under the daily schedules that occur, and which can be simplified during early design. A simulation-based comparative approach was selected because it permits the isolation of interactions among envelope, glazing, orientation and schedules under a fixed climate and consistent system assumptions.

Simulations were executed in a case study in Eilat, located at the southern tip of Israel. It has a hot, arid climate with pronounced solar loads, making it a useful testbed for schedule–envelope interactions**.** Three building archetypes were modelled to represent the family, hotel employee and student dwellings. For each configuration, an occupant profile defined the hourly presence for weekdays and weekends, the use of appliances and lighting during presence as well as thermostat setpoints, such that HVAC systems operated exclusively during occupied hours and remained off when spaces were unoccupied. Simulations were run with the EnergyPlus engine via the DesignBuilder interface for Eilat's climate. Annual cooling electricity consumption, normalized by floor area, served as the primary outcome; peak sensible loads and annual heating electricity were tracked for completeness.

3 Methodology

The case study includes three buildings located in the Ye'elim neighborhood in Eilat, Israel. This ensures that climate and much of the urban context are comparable while occupant profiles differ. The occupied floor areas are approximately 810.5 m^2 for the building housing families, 1,945.8 m^2 for the building housing hotel employees, and 1,534.8 m^2 for the building housing students. Facade glazing differs in ways that are consequential: in the building housing families glazing is concentrated on the north and south, with very little on east and west; the building housing hotel employees has more glazing on east and west; the student building has a low overall WWR with modest glazing on all façades (Figure 1). These characteristics will explain later why rotating these buildings will yield opposite outcomes in different cases.

1a. The building housing families

1b. The building housing hotel employees

1c. The building housing families

Figure 1. The three buildings included in the case study

Opaque assemblies reflect common local construction methods, and include cemented plaster finishes, concrete blocks or lightweight concrete layers, insulation where applicable and structural elements. Composite wall resistances for the three buildings ranged from roughly 0.43 to 0.84 m^2·K/W, indicating meaningfully different starting envelopes. Two glazing systems bounded performance: an insulated glazing unit with a solar heat-gain coefficient near 0.80, visible transmittance around 0.70 and a U-value near 4.5 W/m^2·K; and a laminated glass near 6 mm with a solar heat-gain coefficient about 0.83, visible transmittance near 0.88 and a U-value near 5.8 W/m^2·K.

Internal gains were set to realistic values for the uses considered. Lighting power density was around 9 watts per square meter and occupant density near 0.04 person per square meter. Equipment gains followed the occupant profiles. Cooling and heating setpoints were 24 °C and 20 °C during occupied periods. A fixed coefficient of performance near three represented cooling efficiency across simulation runs so that differences in results reflect envelope, glazing, orientation and schedule effects rather than changes in plant performance.

Occupancy schedules for families were derived from field surveys, reflecting weekday absences and evening presence; hotel employee occupancy schedules were taken from shift rosters and reflect daytime presence in accommodation; student occupancy schedules were collected by survey and document extended afternoon and evening study with associated appliance and lighting use. The schedules were applied consistently across simulations to preserve comparability.

Five sets of building energy simulations were run to isolate, in sequence, the dominant physical and behavioral drivers of cooling energy demand in a hot-dry climate without introducing unnecessary parameters:

1. The first simulation set establishes a baseline for end-use intensities in each type of building occupant and provides an anchor for subsequent changes and comparisons.
2. The second simulation set was run after the occupant schedules of each building were swapped, to separate envelope physics from user behavior, and ensure that subsequent geometric changes can be correctly interpreted.
3. Orientation and per-façade glazing are examined because they are low-cost, early-stage choices with large leverage in cooling-dominated climates, and because their benefits depend on when people are present.
4. Insulation thickness is adjusted, since it governs conduction one hand, yet in better-performing walls the slope of savings flattens beyond mid-range thicknesses, so knowing occupant-type-specific thresholds prevents over-investment.
5. Benchmarking against local and ASHRAE standards allows translating the occupant-sensitive results into the language of codes and rating schemes familiar to decision-makers.

Each simulation thus answers a distinct question that practitioners routinely face in renovation: how large are the loads to begin with; how much of the variation is behavioral rather than stemming from the building design; which early-stage geometric choices matter most; how far to carry insulation before returns diminish; and how the results compare to regulatory archetypes used for compliance.

All simulations used a single weather file representative of Eilat's hot, dry climate and common comfort setpoints with unoccupied setbacks. Lighting density, occupant density and equipment gains followed the specified profiles uniformly across simulations. Domestic hot water was excluded from comparisons to keep the focus on how presence, envelope and solar gains interact. This omission does not affect the relative ranking of envelope and façade measures for cooling electricity, and furthermore domestic hot water is primarily generated with solar thermal systems. HVAC efficiency was intentionally held constant to avoid conflating equipment upgrades with envelope and schedule effects; specifically, no complex HVAC systems were modeled. Instead, heating and cooling loads were represented using the Ideal Loads Air System with a fixed COP of 3, ensuring that results reflect only building-physics measures under consistent plant assumptions.

4 Results

Simulation 1 sets the baseline against which changes can be interpreted. In the building housing families, the annual total energy consumption of 85 kilowatt-hours (kWh) per square meter (m^2) reflects a balance in which equipment and cooling are the dominant components. The building housing hotel employees, displays a slightly lower consumption in total in terms of kWh per m^2, because heating is negligible and cooling is slightly lower despite similar equipment and lighting intensities. Consumption in the student building rises to about 95 kWh per m^2 in total; the gap relative to the other two is driven primarily by cooling, which is roughly 6-7 kWh per m^2 higher, corresponding to an increase on the order of 18-20%. Such an increase is potentially substantial for decision-making because, at campus scale, it can map to large absolute differences in consumption and peak demands.

Simulation 2 demonstrates that behavior alone can shift outcomes by magnitudes comparable to envelope changes. In the building originally housing families, substituting for the student occupancy schedule increases cooling from about 32.2 to roughly 43.8 kWh per m^2, an increase of almost 36%, while heating increases modestly (Figure 2). In the building housing hotelemployees, the same substitution raises cooling from about 31.3 to approximately 39.7 kWh per m^2, an increase of around 27%. In the student building, moving from the student schedule to the family schedule reduces cooling by about 24%. The persistence of these variations across all three building geometries suggests that retrofit packages should be tailored to specific user groups; otherwise, a package optimized for one schedule may underperform for another even in the same physical building.

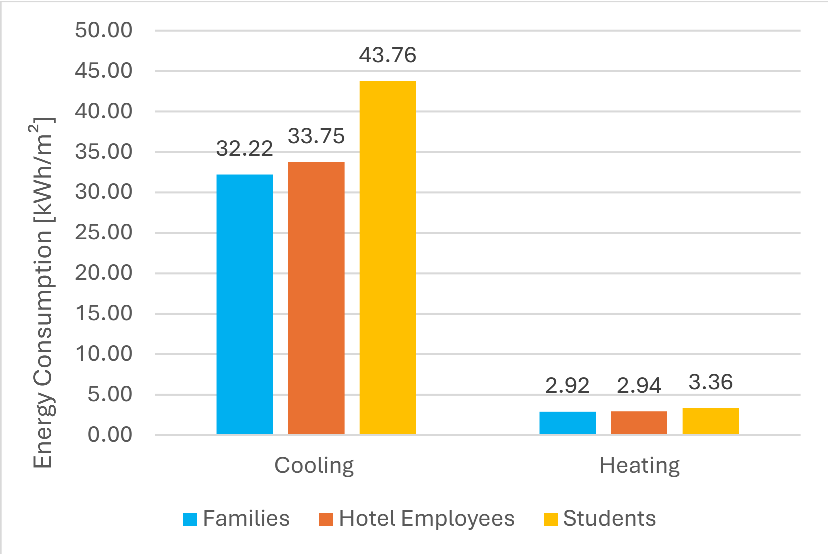


Figure 2. Cooling and heating energy consumption when substituting occupancy schedules in the building housing families

Simulation 3 quantifies how building orientation interacts with facade glazing and schedules. In the family building, a ninety-degree rotation of the building *increases* cooling by roughly 10-11%, irrespective of the schedule, shifting the family case from approximately 32.2 to about 35.8 kWh per m^2 (Figure 3). In the hotel-employee building the same rotation *reduces* cooling by roughly 8-9%, moving the family case from approximately 30.0 to about 27.5 kWh per m^2. Such opposing results can be linked to the distribution of glazing: when east and west carry larger window shares, rotation that mitigates their afternoon exposure during typical presence reduces cooling; when north and south dominate, the rotation can expose larger east–west areas at the wrong times. These outcomes imply that orientation guidance must be expressed alongside WWR, not as a stand-alone rule.

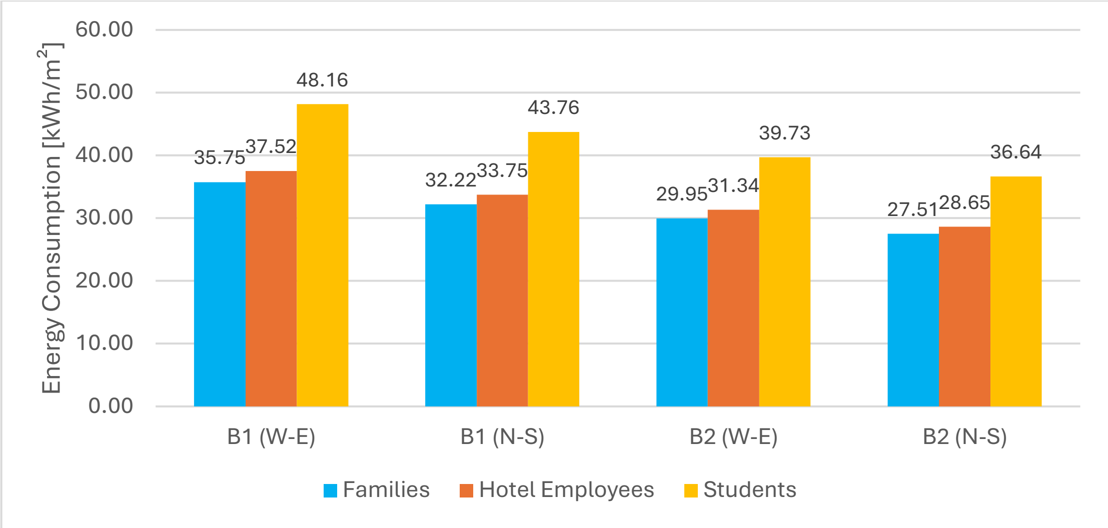
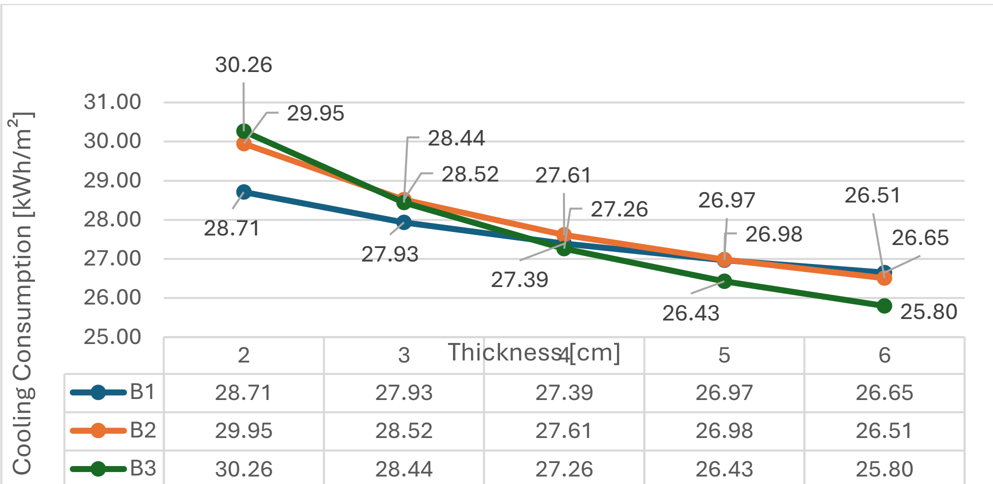


Figure 3. Cooling energy consumption when the family building (B1) and hotel employee building (B2) are rotated, under the different occupancy schedules

Simulation 4 clarifies to what extent additional insulation is justified. On the hotel employee building, increasing EPS-30 insulation thickness from 2 to 3 centimeters cuts cooling by about 1.5 kWh per m^2; increasing it from 3 to 5 the reduction is another 1.6; and further increases show declining gains. The slope thus flattens as thickness rises, with marginal savings dropping below a third of a kilowatt-hour per m^2 per cm beyond six centimeters. On the student building, the early increments are larger - reducing by about 2.5 kWh per m^2 from 2 to 3 centimeters and by about 2.8 kWh per m^2 from 3 to 5 centimeters - before flattening when additional thickness of insulation is added. At a fixed 6-centimeter thickness of insulation, the family schedules across building geometries cluster around an energy consumption of 26-27 kWh per m^2 (Figure 4), the hotel employee schedules around 27-28 and the student schedules in the low-to-mid 30s. This supports the notion of carrying insulation to the point where slopes fall below project-specific thresholds and then turning attention to glazing and shading.



	2	3	4	5	6
B1	28.71	27.93	27.39	26.97	26.65
B2	29.95	28.52	27.61	26.98	26.51
B3	30.26	28.44	27.26	26.43	25.80

Figure 4. Cooling energy consumption when the insulation thickness is increased in each building (family building – B1, hotel employee building – B2, student building – B3) and under the family occupancy schedule

Simulation 5 benchmarks aggregate results against Israeli and ASHRAE standard archetypes. Lighting and plug-load intensities under ASHRAE are much higher than under Israeli assumptions, and these differences drive large gaps in the total consumption for each building (Figure 5, where B1 is the family building, B2 the hotel employee building, and B3 the student building). The exercise emphasizes that benchmarking should be interpreted considering the schedules embedded in the archetypes; occupant-sensitive schedules can bring results closer to what will actually occur in operation. This is currently ignored by standards, which treat the occupancy schedules of residential buildings in a uniform way, despite the significant impact in building energy consumption of the actual schedules of different types of residential building occupants. As a result, simulations that are based on the archetypes required for compliance may be misleading when guiding building renovation design choices.

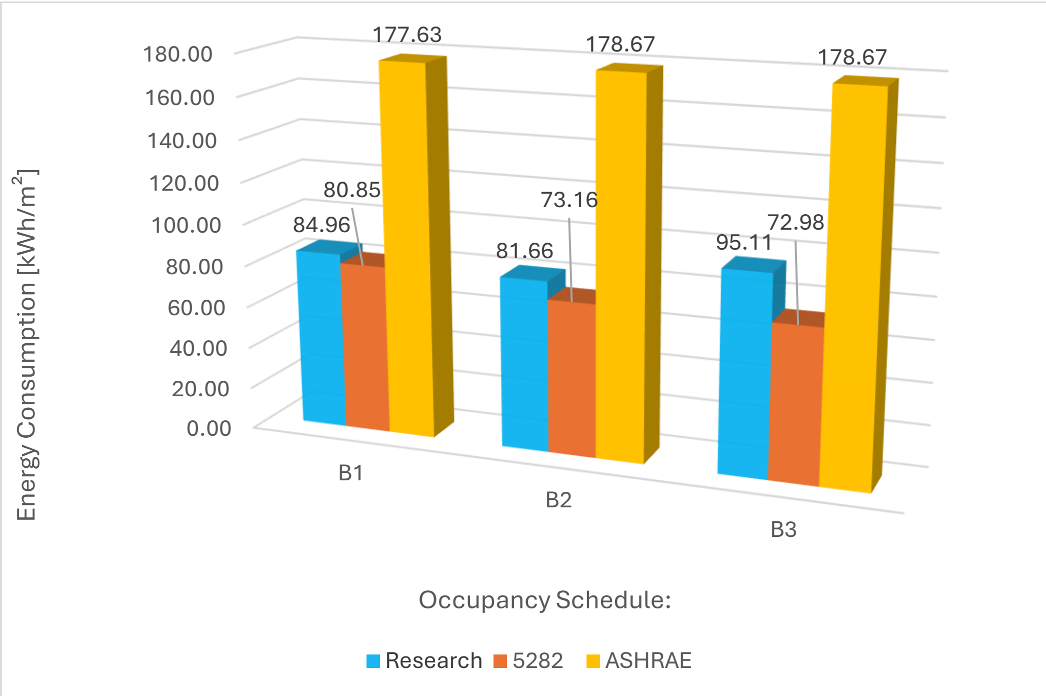


Figure 5. Total energy consumption when the occupancy schedules for the original building occupants are determined according to this study's empirical findings, according to SI 5282, and according to ASHRAE

To summarize, across simulations several relevant regularities emerge. The timing of occupant presence in the building relative to solar exposure determines whether changes in building orientation will help or harm in terms of energy consumption, because facade window shares mediate gains. Insulation exhibits clear diminishing returns whose thresholds vary with occupancy schedules: groups with greater overlap between presence and peak heat benefit from slightly higher levels before the curve flattens. Finally, behavior alone introduces variations in cooling electricity demand large enough to reorder the attractiveness of alternative retrofit packages. Renovation strategies should therefore be developed with explicit reference to the intended occupant group and its daily rhythm. This, however, seems not to be adequately addressed in current standards.

5 Conclusions

The findings support an occupant-sensitive approach to renovation design in cooling-dominated climates. When schedules are represented realistically, measures for adjusting building envelope and façade design can be prioritized with greater confidence. Orientation and facade glazing areas emerge as consistent factors, while insulation thickness should be sized to the point where marginal savings flatten for the particular type of building occupant. Because behavior introduces variations in cooling electricity comparable to many physical changes, schedule selection must be treated as a primary modelling decision in both design and benchmarking.

The results of the simulation runs in the case study show that for the user groups with substantial midday presence, the recommended emphasis is on east–west façade control-external shading and selective glazing-combined with insulation carried somewhat beyond the levels that would be optimal for groups with less midday presence. For the groups typically away during peak heat, carefully managing facade WWR and glazing together with thermostat delivers a large share of the achievable savings at lower cost. For mixed or shift-driven building occupants a balanced package is appropriate, and administrative allocation policies can capture operational improvements even before physical retrofits are implemented. Finally, the findings highlight that energy simulations that are based on the occupancy schedules required for compliance with current standards may be misleading when guiding building renovation design choices.

Future research could combine measured presence and device-level data with explicit uncertainty treatment to strengthen early-stage decision support. Extending the analysis to additional climates and building types will test generalizability. Coupling cost, constructability and embodied carbon considerations will enable multi-objective tradeoffs that reflect real-world constraints.

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