# Integration of diverse occupant profiles in office design decisions

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## Abstract

A successful building design must prioritize high indoor environmental quality (IEQ) to ensure occupant comfort. Previous studies frequently neglect that occupants differ in their needs and preferences during the design phase. This study introduced a workflow to integrate occupant diversity in design, then it assesses the impact of accounting for diverse occupants in the selection of architectural design parameters. To accomplish this, eight profiles for potential occupants were created, each with distinct IEQ preferences and occupancy schedules. A parametric study was then conducted for an office room in Ottawa, comprehensively addressing all domains of comfort and exploring design possibilities tailored to each group's satisfaction. The findings from this case study reveal that different occupant profiles may require specific design attributes. Through comparing a range of design scenarios, this research highlights the importance of designing adaptable and flexible buildings with various zones that accommodate occupant diversity. The insights from this study can guide policymakers in facilitating human-centered decision-making in the early stages of design.

## Introduction

Ensuring occupant comfort is paramount, particularly in office settings, as it directly impacts the health and productivity of workers. Studies reveal that dissatisfaction persists among occupants, even in buildings that meet recommended standards (Bluyssen et al., 2015), underscoring the diverse needs and preferences of individuals.

Nowadays, there is a notable shift towards personalization, recognizing the unique needs and preferences of individuals. This trend, commonly observed in product and service customization, extends to the realm of building design, where accommodating diverse occupants is increasingly crucial for enhancing their well-being and effectiveness.

However, meeting the needs of users in buildings, particularly in environments like offices where occupants do not select their space, and where occupants may change over time, poses challenges. Recent research has begun to integrate occupants more explicitly into the design process, with a focus on modelling occupants to better understand their needs and behaviours (Azar et al. 2020). The traditional approach has often centered around modelling a "typical occupant" for building simulations, overlooking the diversity between occupants. This oversight may lead to a shortfall in achieving high levels of occupant satisfaction within buildings.

The concept of "occupant diversity" acknowledges and embraces variations among individuals who inhabit or utilize a building (O'Brien and Gunay, 2016). While research exploring occupant diversity has primarily focused on behavioural aspects and their impact on energy consumption, there is a growing recognition of the need to consider other factors such as preferences related to IEQ.

Research has delved into the behavioural aspects of occupant diversity and their impact on energy consumption (O'Brien et al., 2017). For example, Veillette, Rouleau, and Gosselin (2021) explored occupant behaviour profiles and examined the impact of the window-to-wall ratio on thermal comfort in residential units, highlighting the diverse effects of different profiles depending on this ratio. Similarly, Karjalainen (2016) conducted numerical simulations for an office, assessing three behaviour types ("careless," "normal," and "conscious") and two design types ("ordinary" and "robust"). Notable efforts have been made to understand occupancy patterns and schedules to seamlessly integrate occupant diversity into the design process (Happle, Fonseca, and Schlueter, 2020). Failure to consider the diversity in occupants' schedules has been highlighted as a limitation in simulation models, leading to a lack of representative ranges of possibilities (Tahmasebi and Mahdavi, 2017). Recognizing the profound influence of occupants on design decisions, it becomes crucial to incorporate other occupant parameters beyond behaviour. Some studies extend their exploration into occupant diversity by examining preferences related to IEQ. Lee et al. (2017) emphasize that "Different people prefer different thermal conditions". In another research Xiong et al. (2018) and Heydarian et al. (2017), investigate differences in visual preference among occupants, revealing various visual satisfaction profiles. Clustering algorithms have been employed to categorize occupants based on various

criteria, revealing the feasibility of grouping them into profiles (Kim and Bluyssen, 2020). Collectively, these studies underscore the variability in people's preferences and needs, indicating the possibility of having various profiles. A proven and effective method for addressing occupant diversity and adopting a human-centered design approach is the development of occupant profiles (Philip Agee et al., 2021).

Personas offer a powerful tool for designers to tailor spaces according to occupants' specific needs, thereby shifting the emphasis away from evaluating designs solely based on factors like initial cost, energy efficiency, or aesthetics (Long, 2009). Crafting personas involves the creation of fictional characters that embody various user types, enabling designers and developers to gain a deeper understanding of user needs, preferences, and behaviours. Persona creation typically involves one of three primary methods: qualitative personas, quantitative personas, and mixed-mode approaches (Mulder and Yaar, 2006). Victoria Haines and Mitchell (2014), applied personas to owner-occupier householders in the UK to understand attitudes and behaviours, aiding energy renovation policy development. Agee et al. (2021) utilized a multifaceted approach to create data-driven personas from US housing units, guiding human-centered design in buildings and infrastructure for both senior and non-senior demographics. Goldstein and Khan (2010) employed personas in building simulation to study occupant behaviour in office buildings, though the method primarily focused on scheduling aspects and lacked considerations for comfort. McCracken, Harpe, and Di Ruvo (2019) developed personas for older individuals with dementia, considering a range of factors including age, culture, socio-economic status, therapy, and sensory input, offering insights for architectural design.

While user profiles and personas hold promise, the literature suggests their integration into building design, particularly in office spaces, remains largely unexplored. There is a notable absence of studies leveraging personas for early-stage design decisions, with personas typically reserved for post-occupancy evaluations or tasks like building automation and energy feedback dashboards. Yet, their full potential could be realized if integrated into the conceptual design phase. Moreover, existing persona creation processes often lack comprehensive consideration of various user characteristics, primarily focusing on attributes related to energy consumption like occupancy patterns. This underscores a significant gap in the literature regarding the proactive inclusion of user-centric considerations in the initial stages of building design. Additionally, there is a research gap in understanding how design variables impact building performance when considering a diverse range of potential occupant profiles.

This study aims to address these gaps by introducing an integrated approach to accommodate diverse occupants' preferences and needs in the design process. Unlike conventional methods that focus on the comfort of typical users, this approach involves establishing diverse occupant profiles and tailoring designs accordingly. Next, it examines whether design choices made in the early stages are affected by the inclusion of different occupant types, using a case study. This comprehensive design approach, offers valuable insights for future research and practice to improve the indoor environment. Figure 1 shows the conceptual framework introduced in this study.

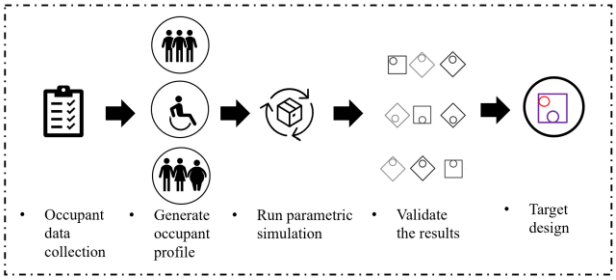



*Figure 1. Conceptual framework to support occupant-centered indoor space design decision-making at early stage.*

## Methodology

This study presents a simulation-driven workflow that leverages available software tools to seamlessly integrate occupant profiles into the design process.

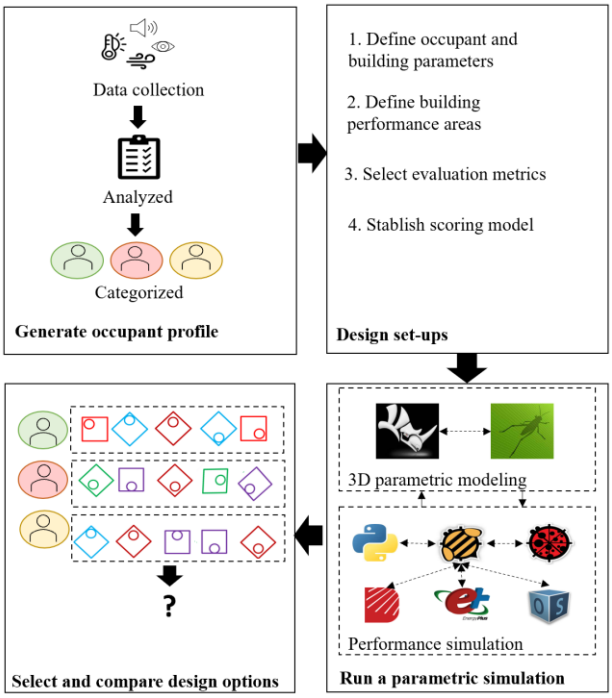



*Figure 2. Proposed design process for occupant-integrated design.*

The parametric approach initiates by gathering data on occupants to construct distinct user profiles. Subsequently, design parameters requiring further exploration are identified, and a scoring system is devised for each profile

based on their preferences and needs. Following this, a list of building performance indices that are important for the designers (e.g., indoor comfort, energy, GHG emissions, etc.), along with their evaluation metrics, is compiled. Parametric simulations are then executed to generate all potential design options and assess their performance metrics using a unified programming tool to avoid complexity. The final step entails comparing and exploring these design alternatives to determine the optimal choice.

The inclusion of diverse occupant profiles affects two key elements of this workflow. Initially, the simulation process necessitates the integration of distinct occupant characteristics for each profile, including metabolic rate, clothing level, and occupancy schedule. Subsequently, a customized scoring model is implemented for performance assessments, considering profile preferences. For instance, if a specific occupant profile places greater emphasis on comfort rather than energy efficiency, its corresponding weight should be assigned accordingly to reflect this preference in design selection.

Additionally, a case study is conducted using the proposed workflow to investigate whether occupant diversity during the design stage influences the determination of architectural design parameters. This methodology offers designers a deeper insight into how their decisions affect both occupants and buildings. Its streamlined nature facilitates the swift and efficient inclusion of occupants in the design process. Allowing designers to evaluate and compare designs across various occupant profiles, equips them with the tools to make informed decisions and enhance their design outcomes. Figure 2 shows the framework used in this study.

## Case study

In order to explore design alternatives across different profiles and evaluate how the inclusion of diverse occupant profiles influences design choices, a parametric simulation of a shoe-box office space in Ottawa was conducted using the proposed workflow.

Focusing on the significant impact of IEQ parameters on occupant satisfaction in workspaces, alongside the increasing emphasis on energy consumption in buildings, the evaluation centers on performance metrics related to indoor comfort and energy efficiency. Specific design factors affecting both energy consumption and comfort levels are examined through parametric simulations.

This study selected various design parameters—such as WWR, orientations, shade types, window materials, occupancy schedule, and office room heights—which influence both energy usage and comfort, serving as the variable design parameters under examination.

### Prototyping occupant profiles

This case study delves into the examination of how accounting for different occupant profiles influences the final decision-making process. To this end, eight distinct personas have been created and examined. Prior research has shed light on the diversity of occupant preferences and requirements across various IEQ domains. Consequently, a select few occupant types have been identified for focused analysis: The first group identified is the Visual-Enthusiast (VE), individuals who prioritize the visual elements of their workspace, considering them pivotal to their overall satisfaction and productivity. Following them are the Thermal-Enthusiasts (TE), who prioritize thermal comfort, preferring environments with consistent and comfortable temperature and humidity levels. Then, there are the Energy-Enthusiasts (EE), who emphasize energy efficiency and sustainability in their workspace design, valuing environmental impact and conservation efforts. Lastly, there are individuals who equally value all four IEQ domains_ visual, thermal, acoustic, and air quality_ related comfort. They seek a harmonious and balanced environment. Additionally, each occupant type is characterized by two distinct schedules, morning, and evening preferences. For instance, $TE_M$ represents the Thermal-Enthusiast profile with a morning schedule, while $TE_E$ indicates the Thermal-Enthusiast profile with an evening schedule. Figure 3 shows the eight occupant profiles assumed for this study.

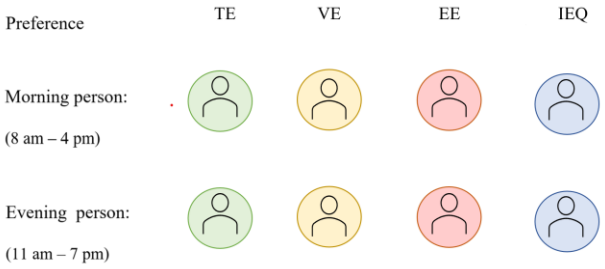



*Figure 3. Different occupant profiles were used in this study.*

### Simulation process

The office modelling and simulation process was developed and run within Grasshopper which is a graphical algorithm linked to Rhinoceros 3D. Grasshopper plug-ins like Ladybug, Honeybee, EnergyPlus, and Python inside Grasshopper were used to calculate visual comfort, thermal comfort, acoustic comfort, air quality, and energy consumption metrics. The comfort metrics were justified and evaluated based on the process used in Fathi and O'Brien (2023), and summarized in Table 1. Next, the Colibri plugin was used for iterating through all variables and performing the parametric simulation. The metrics were standardized on a scale of 0 to 10 using the linear method outlined in Fathi and O'Brien (2024), facilitating straightforward comparisons.

To model the office (Figure 4), the entire office room was treated as a single thermal zone and the air within the space was assumed to be uniformly mixed. Table 2 and Table 3 presents simulation parameters assumed to be

fixed and design variables along with their values, respectively. Conducting a parametric study based on the defined variables for each parameter, a total of 192 design solutions were analysed. Except for the building's façade, all other surfaces were presumed to be adiabatic. The material properties of the walls and windows are shown in Table 4 and Table 5, respectively. The simulation was carried out for a full year, utilizing average hourly calculations based on the morning and evening occupation period defined. The simulation is carried out in Ottawa, representing climate zone 6, according to ASHRAE Standard 169 (2021).

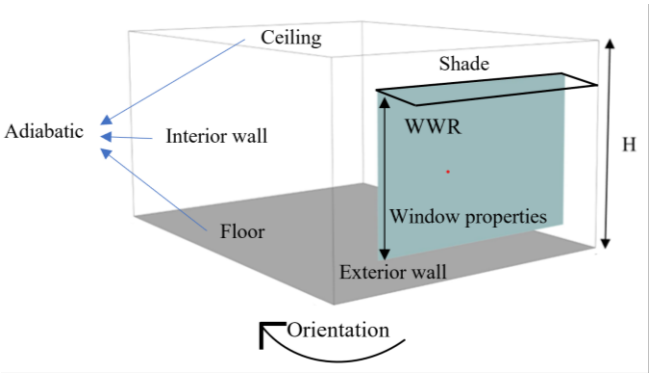



*Figure 4. 3D view of the model.*

*Table 1. Comfort metrics, their evaluation methods, and goals used in this study.*

| Domain | Metric | Assessment | Goal |
|---|---|---|---|
| TC | PPD | $PPD = 100 - 95 * \exp[-(0.033PMV^4 + 0.2179PMV^2)]$ | < 10% |
| VC | sDA | Moderate | > 55% |
| | UDI | Moderate | Maximize |
| | sGA | High | Maximize |
| AC | RT | $RT = Volume / (6 * Sound\ absorption_{Tot})$ | ~ 0.6 s |
| | SPL | $SPL_{inside} = SPL_{Outside} - Sound\ attenuation_{Tot}$ | < 40 dB |
| IAQ | $CO_2$ | $PD_{CO_2} = 395 * \exp(-15.15.\ C_{CO_2}{}^{-0.25})$ | < 700 ppm above outdoor |
| | VOC | $C_{VOC} = (specific\ emission\ capacity \times area\ of\ the\ emitting\ surface / Volume\ of\ the\ room) / air\ exchange\ rate$ | < 500 µg/m$^3$ |

*Table 2. Values assumed for the simulations.*

| Attributes | Values |
|---|---|
| Climate data | Climate zone 1, 6 |
| Occupancy schedule | ASHRAE Standard 90.1 |
| Occupant activity | Sitting |
| Metabolic rate | 1 met |
| Clothing level | Based on outdoor temperature |
| Ventilation rate per area | 0.0003 m$^3$/s.m$^2$ |
| Infiltration rate per area | 0.0002 m$^3$/s.m$^2$ |
| Equipment load density | 6.88 W/m$^2$ |
| Lighting power density | 6.67 W/m$^2$ |
| HVAC system | VAV gas boiler with reheat |
| Outdoor $CO_2$ concentration | 420 ppm |
| $CO_2$ generation | 26000 mg/met |
| Cooling setpoint | 24°C |
| Heating setpoint | 21°C |
| Heating setback | 15.5°C |
| Cooling setback | 29.5°C |
| Spatial daylight illuminance threshold | 500 lux |
| UDI thresholds | 300 and 3000 lux |
| Noise from street | 65 dB |
| Noise from neighbouring offices | 55 dB |

*Table 3. Design parameters and the ranges.*

| Parameters | Variables | Attributes | Number of values |
|---|---|---|---|
| Office Geometry | Height (m) | 2.7, 4.2 | 2 |
| | Width (m) | 3.5 | 1 |
| | Depth (m) | 6 | 1 |
| | WWR (%) | 0.2, 0.4, 0.6 | 3 |
| Office façade | Orientation (°) | 0, 90, 180, 270 | 4 |
| | Shade (m) | 0.07, 0.00 | 2 |
| | Window type | | 2 |
| | Wall type | | 2 |
| Total cases | | | 192 |

In the end, eight design options with the highest comfort levels specific to each profile were selected and compared. For instance, for the TE profile, eight designs that provide the highest thermal comfort were chosen. Likewise, the top eight designs with the highest visual comfort level were chosen for the VE profile. Designs with the lowest energy consumption were selected for the EE personas, while the average value of all four IEQ components served as a metric for selecting design options for the IEQ personas.

*Table 4. Material properties of walls, floor, and ceiling.*

| Type | RSI ($m^2K/W$) | Sound absorption coefficient | $\varrho_{wall}$ (kg/$m^2$) | VOC emissions (mg/$m^2h$) |
|---|---|---|---|---|
| Wall type 1 | 2.34 | 0.06 | 500 | 0.025 |
| Wall type 2 | 4.2 | 0.10 | 200 | 0.202 |
| Floor | - | 0.15 | - | 0.60 |
| Ceiling | - | 0.70 | - | 0.17 |

*Table 5. Material properties of window*

| Type | USI ($W/m^2K$) | SHGC | VT | Sound absorption coefficient | Sound attenuation (dB) |
|---|---|---|---|---|---|
| Window 1 | 1.76 | 0.68 | 0.74 | 0.2 | 15 |
| Window 2 | 0.68 | 0.31 | 0.54 | 0.2 | 40 |

## Results

Overall parametric simulation of 192 different design scenarios for considering different WWR, orientations, shade types, window materials, occupancy schedule and heights of the office room was run for Ottawa city.

Figure 5 Comparing different profiles reveals subtle distinctions in design options for morning and evening profiles, except the TE profile. Within the TE category, evening designs consist solely of south orientations with variations in WWR. However, for morning profile designs, most are oriented towards the north, with few options towards the east and south featuring smaller window sizes. Regarding WWR preference, EE profiles show a preference for smaller windows. Conversely, VEs consistently favour larger windows on the north side of buildings, aligning with both morning and evening preferences. This trend mirrors the designs for the IEQ profiles, with the exception of one design in the evening schedule oriented towards the west with 60% WWR. The visual comfort levels of all designs, as assessed in this study, are generally not high. Therefore, to achieve better average comfort for the IEQ profile, which encompasses all four domains of comfort, the emphasis remains on designs with superior visual comfort that demonstrate acceptable performance in other domains.

This method, involving distinct profiles, allows for the generation of sets of optimal design solutions for each persona, which can then be compared. It becomes the designer's responsibility to determine how to utilize this information to craft a comprehensive design that caters to the preferences of the majority of personas. One approach is to create different zones tailored to various profiles. For instance, a building with multiple spaces each with specific attributes to satisfy different profiles. However, in cases where having diverse designs in separate zones is not feasible, and a single design is required for various profiles, a critical question arises: how can designers support such a unified design? One strategy is to prioritize features that satisfy the preferences of most individuals. Alternatively, designers can pursue a design option with the highest acceptability level across all profiles. In this situation, each selected design for every profile could receive a score, which would then be arranged based on the total score across all profiles to identify the most favourable option.

An alternative effective method for exploring different profiles involves comparing the optimal designs attained for each profile category and assessing if they can be grouped into distinct categories with comparable design preferences. In this context, the percentage of overlap between the selected designs serves as a metric indicating the degree of similarity between different profiles and occupancy schedules. Figure 6 illustrates this percentage of overlaps for TE, VE, EE, and IEQ profiles. It is evident that morning and evening profiles show a high overlap percentage. Additionally, EE and TE profiles can be grouped due to their similar preferences, while IEQ and VE profiles form a distinct group. Designers can then identify the most frequently occurring design options and compare them to determine the final design strategy.

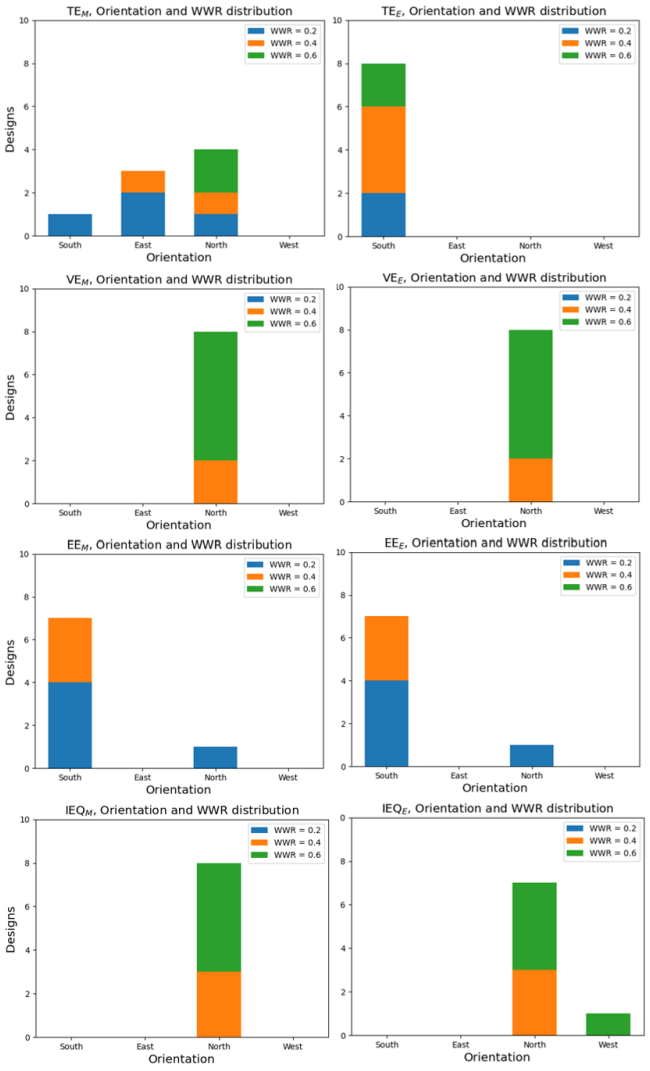



*Figure 5. Distribution of WWR and orientation among various occupant profiles for climate zone 6 (Ottawa).*

In Figure 7, the average total comfort and energy usage across various profiles are depicted. The total comfort level spans from 6.3 for the $TE_M$ profile to 7.7 for the $IEQ_E$ profile. Notably, the IEQ and VE profiles, while achieving superior comfort levels, exhibit relatively higher energy consumption compared to other profiles. In general, evening designs appear to be slightly more comfortable, except for the VE profile, where morning designs achieve a marginally higher total comfort level. Regarding energy usage, the VE profile consumes the most energy at around 200 kWh/m$^2$, followed by the IEQ profile, the TE profile, and lastly the EE profile with an energy usage of around 130 kWh/m$^2$.

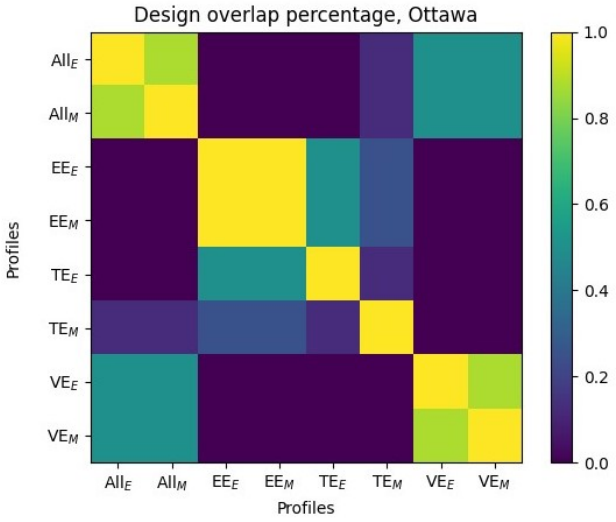
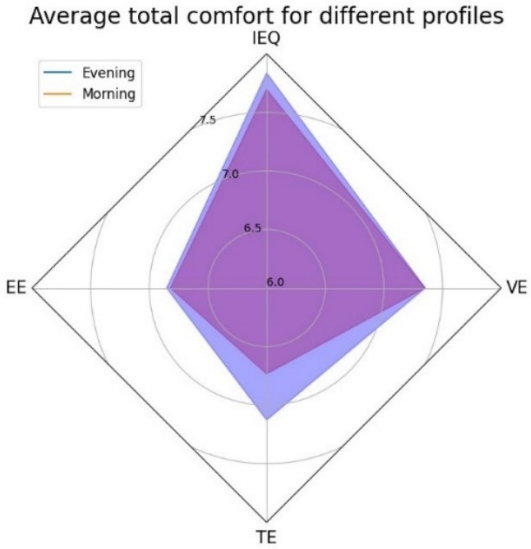



*Figure 6. Overlap between best designs for different profiles and schedules.*



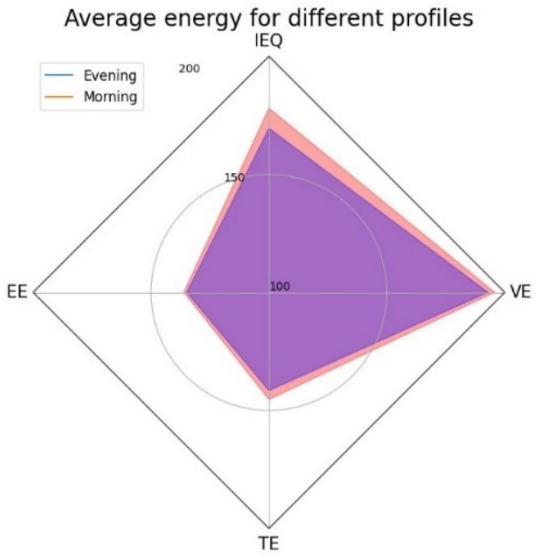



*Figure 7. Average total comfort and energy usage (kWh/m^2) in different profiles.*

## Limitations and future work

This study identifies several limitations that warrant careful consideration. The profiles created and employed in this study are limited in scope and have not been validated with real-world data. However, the primary objective of the study was not to develop authentic personas for office users but rather to showcase the incorporation of various occupant types into the design process and assess their influence on design decisions. As a result, only a select sample of profiles with distinct preferences was utilized in this context. Yet, tapping into extensive datasets from sources such as TUS and Google Maps data, coupled with the utilization of advanced text mining techniques for social media analysis, could offer a more comprehensive validation of the profiles and their correlation to real-world figures.

Furthermore, the study's assessment of satisfaction was limited to a narrow range of metrics. For instance, visual comfort was evaluated solely based on daylighting metrics, neglecting other influential factors like view and aesthetics. Thus, future research should explore a broader spectrum of metrics to provide a more comprehensive understanding. In addition, future research should prioritize the development of efficient methods for collecting and categorizing occupant data. It's crucial to explore the feasibility of integrating these considerations into real-world architectural practices, considering potential challenges, economic implications, and overall sustainability. Such investigations can offer valuable insights into adopting a more inclusive and tailored approach to building design, ensuring it meets various occupant needs while remaining feasible within budget and resource constraints.

## Conclusion

To enhance both human well-being and operational efficiency within buildings, it is crucial to incorporate occupants into the design process. Yet, the diverse range of human needs and preferences is frequently neglected by professionals. This study seeks to address this gap by developing a methodology for integrating diverse occupant profiles into building design, with a specific focus on office spaces. Consequently, a comprehensive building design framework is introduced, aiming to incorporate occupant diversity and assess building performance holistically. A case study was conducted to demonstrate the proposed workflow, using parametric simulation to investigate different design options according to various occupant profiles at the design phase for an office room located in Ottawa.

The findings underscore how the influence of occupant profiles on design decisions varies depending on their characteristics. Different types of occupants may necessitate different design approaches, although some designs may accommodate multiple types effectively. Thus, designers must employ a systematic and thorough process for comparing and adapting designs to cater to diverse occupant profiles early in the design phase. This can involve creating various zones or selecting designs that cater to different occupant types, ultimately promoting better indoor environments. Furthermore, based on the specific case study investigated in this study, implementing a specific schedule for occupants may not always be essential across main design variables. These results can also refine guidelines and standards, shifting the focus from mere occupancy numbers to prioritizing the needs of occupants during the design phase. This entails emphasizing the development of spaces that cater to diverse occupant profiles and considering a range of scenarios that occupants may encounter within the built environment, including varied usage patterns, activities, and preferences.

This methodology empowers designers to understand performance variations of designs for diverse occupants, enabling them to identify solutions that cater to different user groups. Overall, the findings obtained from this study have the potential to enhance human-centric decision-making during the early stages.

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