Personas to understand buildings occupant behaviour and energy usage

Vinu Subashini Rajus[1], Liam O'Brien[2], Gabriel Wainer[1]
[1]Department of Systems and Computer Engineering, Carleton University, Canada
[2]Department, of Civil and Environmental Engineering, Carleton University, Ottawa, Canada

Abstract

Advanced occupant modelling facilitates understanding occupant behaviour by providing dynamic behaviour hypotheses. Most advanced models do not consider occupants' complex nature like adaptive knowledge, attitudes, available control, interactive behaviour, and available technology. This paper proposes a persona-based approach to capture various occupant characteristics for building design, simulation, and automation. We demonstrate a method to integrate the personas in building performance simulations for thermal preference in an academic office context. The case study illustrates the ease and flexibility in applying personas for different use case scenarios for decision-making. The energy usage is 10% higher or 12% lower than the standard assumptions based on the personas revealing occupants' do matter in a design.

Key Innovations

- We propose a framework for personas to understand and consider occupant behaviour for comfort.
- We include an implementation of persona in a computer-aided design tool for design and performance analysis.
- It presents a case study showing the application of personas for building performance simulation (BPS)

Practical Implications

We provide personas as an approach to consider various occupant characteristics. The paper describes how to integrate the personas in building simulation tools to understand occupant behaviour's implications on energy usage.

Introduction

Occupant behaviour is a significant aspect of understanding the performance of buildings. Occupants have varying comfort preferences, and various factors influence their behaviour in buildings. Their interactive behaviour often depends on contextual parameters like building type or available controls and personal parameters like clothing preferences, adaptive knowledge, and metabolic levels (Rajus, 2018). Further, occupancy hours vary based on building context. For example, in an academic building, occupancy varies for professors, administrators, graduate, and undergraduate students. Likewise, in an industrial office space, the occupancy hours may be regular or flexible for an office that follows the Results-Only Work Environment (ROWE). Building performance analysis ignores or minimizes the diversity of such occupancy characteristics.

Post-occupancy evaluation of energy-efficient buildings shows unexpected energy usage where occupants are one of the primary contributors. Occupants' behaviour is more complex than the assumptions usually made for building simulation (De Wilde, 2014). Typical assumptions for occupants in energy modelling consider basic static schedules (O' Brien et al. 2017) and this is the most common practice in the building industry. Advanced modelling techniques consider occupants' dynamic behaviour, but this is not typically used by the building industry due to a lack of resources, knowledge, time, and cost in modelling dynamic behaviour and occupants' diversity. Also, occupants' modelling does not consider various individual parameters like occupants' comfort preferences and interactive behavioural aspects in the modelling. Even if the simulation models consider varying occupancy hours, they are, in general, modelled using a uniform approach for all zones. Current studies do not demonstrate different occupant characteristics for different building zones (Abuimara et al. 2020). One of the common approaches in understanding occupants' complex behaviour is using agent-based modelling (ABMs). The occupants' individual preferences, group behaviour, and personal traits can be assigned through autonomous agents (Macal and North, 2015). ABMs enables designers to observe emerging patterns by applying diverse occupant characteristics to the agents, interaction between the agents, and adaptive behaviour. ABMs can help when considering diverse occupant characteristics with environmental context. ABMs are mostly available for domain experts, and the descriptions of ABMs and the assumptions in modelling are not transparent (Berger and Mahdavi, 2020).

On the other hand, fields like human-computer interaction or industry design use personas for design implementation and evaluation. Personas are fictional characters used to capture occupants' characteristics, behaviours, and goals (Cooper et al. 2004). Personas are used to communicate the end-user needs and goals to various design and team members (Long, 2009). Personas capture how people behave within the context (Pruitt and Adlin, 2010). A persona is an approach that can be applied or coupled with other simulation models. Personas are user-centered design constructs that allow the designers to understand user behaviour, goals, and comfort contextually. Personas are not limited to simulation (Agent-Based or others) but also can be used to develop policies, interaction design, and building automation, only to mention a few. Using personas one can drive the design from an end-user perspective. They serve as a design construct for the building industry stakeholders to follow at various stages of building design and construction considering occupant behaviour and comfort. In this research we discuss how to build personas for building simulation, using personas to define occupant characteristics to understand diverse behaviour. We use the Grasshopper/Ladybug/Honeybee modeling and simulation software stack. This popular simulation environment can be used to build personas, enabling designers to evaluate and consider personas at the early design stage.

The rest of the paper introduces persona framework, describing occupant characteristics related to comfort in buildings based on literature. We articulate the need for personas to evaluate building performance and how personas can be implemented in a commonly used building performance tool. The paper discusses the need for personas, a conceptual framework of personas, a design and implementation of persona in Ladybug/Honeybee/Grasshopper, a workflow describing the use of persona for building performance analysis, and a simulation case study of personas for an academic office context. The persona may reveal the potential pitfalls in the design, leading to design solutions.

Related work

Personas have been used in human-computer interaction to understand user behaviour and goals. They are also used for product design (Long, 2009) and developing health policy (Gonzalez de Heredia et al. 2009). In this section, we explain how personas are being used in the building industry and simulation.

In Goldstein et al. (2010), personas were used for building simulation to understand occupant behaviour in office buildings. The authors use the scheduled-calibrated and weighting coefficients method to generate personas. The personas consider occupants' arrival, departure, desk meetings, team meetings, and onsite and offsite breaks. While this method is useful for creating different personas with varying office metrics, it does not show how personas can consider occupant comfort.

Personas were created for architects and designers to create meaningful spaces for older people with dementia (McCracken et al. 2019) through literature review and participatory workshops. These personas consider age, cultural background, socio-economic status, therapy, objects, senses, psychological, cognitive, and physical behaviour. A qualitative study on older people revealed two personas: Moderate Dementia Persona - Annie and Severe Dementia Persona - Susan. They suggest the need for more research to understand the broader population of older people in Australia. Here the personas are created for a specific user type and for designing spaces. The methods can be applied to other contexts like designing for energy-efficient buildings and building performance.

In another context, a set of personas were developed to understand the archetypal owner-occupier families for retrofitting buildings made of a solid wall in UK – homes (Haines and Mitchell, 2014). The persona was created to understand the owner's attitudes, behaviours, difficulties, and process to make home improvements. The study enabled them to understand the opportunities and barriers for retrofitting. Understanding the user issues, allowed them to produce solutions and policies to encourage home improvement.

A more recent study uses the persona-based approach to develop older people's thermal comfort guidelines in South Australia (Bennetts et al. 2020). This method uses hierarchical cluster analysis by collecting data from older people to create thermal personalities. The thermal personalities consider personal characteristics, ideas, beliefs, knowledge, house types, and location. They developed six clusters with different emphasis on cost, health, and well-being, and a combination of comfort and cost, comfort and environment for thermal comfort guidelines. Though these personas were created for older people, the process highlights designing for occupants and occupant behaviour diversity.

Occupants are the key drivers in building performance, and their knowledge of technology, cultural baggage, available technology, and interactive behaviour implicates energy usage (Rajus, 2018). Often these details are not considered in building simulation due to cost, time, and available techniques. Most of the concepts presented here generate or identify personas based on contexts or provides a method to create personas. They are not implemented in design tools for early design analysis. The literature review shows how personas have been used to improve home renovation and designing spaces in the building industry. Bennets et al. (2020) identify six thermal personalities as a guideline for older Australians through the concept of persona, but it is not implemented in any simulation tool. Goldstein et al. (2010) develops personas using the scheduled-calibrated and weighing-coefficients method but is not integrated into the design and simulation tool. This research considers personas for occupants' comfort and comfort-related variables and parameters. It is integrated into a commonly used design and simulation tool for early design analysis. In this study, a conceptual framework shows the need for personas in the building performance simulation (BPS) and describes the persona characteristics related to occupant comfort. Personas are implemented in the Grasshopper/Ladybug/Honeybee tool using Energy Management System (EMS) in EnergyPlus for overriding occupant schedules and preferences.

Persona framework

This section explains four aspects: occupant characteristics for a persona and context implications; personas as a link between design, building performance, and simulation; implementation of personas in building performance tool; and a workflow using personas for energy simulation. The personas framework can be applied for office and residential buildings, but the parameters and values will vary depending on context.

Developing Personas

Personas can be developed for specific use cases by end-user data survey, participatory workshop, or literature review. Bennets et al. (2020), uses a telephone survey and an indoor environmental monitoring/occupant survey for data collection and cluster analysis to identify older people's thermal personalities. This method can be used for designing personas on a project basis. In this research, the characteristics of the persona were derived from a literature review. Information on each parameter can be collected from clients or a user survey for precision, or based on the context, designers can create personas.

Persona characteristics

Thermal preferences: People often express their thermal sensation by their feelings. For example, "I like the building to be cozy or warm" or "slightly cool" or "just right" (Rajus, 2018). Personas can also be applied to Fanger's thermal scale: hot, warm, slightly warm, neutral, slightly cool, cool, and cold. For the current study, we use the thermal expressions of (Rajus, 2018). The persona can capture the adaptive behaviour of the occupants with the building on the scale. For example, what actions would they take if they found the building hot or cold? Will it be energy efficient or not? Do they have access to control the temperature or not? To demonstrate personas' use, we simplify the preference as slightly cool 19°C, just right 21°C, and warm/cozy 24°C. Adequate research is needed to consider thermal preference for large context and arrive at potential ranges and inputs.

Visual comfort: The lighting preference will depend on activity, or it could be subjective to whether occupants prefer a sunny room with more natural light. For example, people who prefer natural light will leave the blinds up unless there are privacy or glare issues, where they need to revert to other options. A person may prefer natural light, artificial light, or both. For instance, a gamer prefers dim lighting compared to a person reading a book during the day. Activity and subjective preference affect the interactive behaviour, which in turn affects building thermal comfort. For example, the blinds are lowered because of glare or privacy issues or up because the occupant prefers natural lighting.

View preference: Views also affect how occupants interact with the building; if the occupants face a natural view, then their blinds may be left open. However, if their view faces another building, privacy may cause them to close the blinds. During design, occupants may prefer an outdoor view, or it may not matter to them. This parameter is very contextual when applied for design, and during a building performance evaluation, it may or may not affect the performance. Nevertheless, this is a parameter that needs to be considered during design.

Occupancy schedules: One of the key parameters for simulating occupant behaviour is the occupancy hours. The occupancy schedules for building simulation assume typical hours, but this may vary based on the building context. For example, the occupancy schedules in an academic context may vary for faculty members, administrators, researchers, or students. There are many models available for advanced modelling of occupancy schedules (Gunay et al. (2016)).

Age groups (Fabi et al. (2012)): The presence of an older person (Bennetts et al. (2020)) or children affects the interactive behaviour in buildings like thermal preference (Rajus & Woodbury, 2019). In a design context, the age will also affect designing for accessibility to controls.

Clothing preference (Gauthier (2016)): it may vary for people. For example, Self (2018), mention that people moving from warmer to colder climates preferred wearing light clothes and cranking the thermostat high. In a residential building, occupants may dress differently. One may prefer to wear a sweater, while another may prefer to dress lighter during winter. People may wear clothes based on the room temperature in an office building if they have no control over the thermostat settings, or wear comfortable clothes and use a space heater.

Activity (Fabi et al. 2012): Activity plays a key role in behaviour as it affects the metabolic level of the occupants. For instance, a person is working on the computer near a window will lower the blind due to glare/direct sunlight. Also, if the occupant has been working on the computer for long hours with no physical break, they may tend to feel cold during winter.

Control opportunities: Interactive behaviour varies in an office setting versus residential. A person has more degrees of freedom to adjust the thermostat settings in a residential building than in an office as they may have no control or partial control. In an office building, the building automation may have more control than the occupants. In this case, occupants may develop other alternatives like adding a space heater to their rooms to keep the space warm during winter.

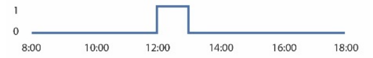
Interactive Behaviour: Interaction behaviour could be active or passive. If the occupants open the blinds, it could be in the same state for the whole month or a year. Active behaviour is when occupants adjust their environment frequently for comfort.

Sustainable behaviour: An occupant who is a *sustainable enthusiast* may be more active in taking actions that are energy-efficient, *moderate* are the people who are in between, "*someone pays, I do not care*, and *I pay, I care*." The person who is paying the bills may consider how the building is operated than a teenager who has no responsibility (Rajus, 2018).

Climatic roots of occupants: Resident or native people may know how to adapt to their weather than a newly immigrated person from a warm climate to a cold country. They carry adaptive knowledge from their country to their new one that is not energy efficient.

Trade-offs: Comfort versus energy, a few people may choose comfort over saving energy. A person who chooses comfort may make choices that may not be energy efficient. Rajus (2018) concludes three types of trade-offs relating to comfort and cost: people prefer comfort over cost, cost over comfort, and there are people who prefer to be comfortable and save energy. The research identifies that comfort preferences of people affect interactive behaviour. If occupants find the building hot during winter, they may slightly leave the window open with the thermostat turned up.

Table 1: Example scenarios of occupant characteristics and their implication on building interaction

Persona Characteristics	**Available Action**	**Behaviour**
Scenario 1: Occupant preferring slightly cool building		
Control opportunities	Window, thermostat	Tendency to open windows for immediate comfort
	 Window state based on control opportunities	
Sustainable Behaviour	Enthusiast, moderate, someone pays I do not care, I pay I care	Someone pays, I do not care attitude leads the occupant to leave the windows open with heat on
	 Window state based on sustainable behaviour	
Trade-offs	Prefers comfort over cost, prefers cost over comfort, be comfortable and save energy	Prefers comfort over cost. Actions are not sustainable like leaving heating and windows on
	 Window state based on trade-offs	
Scenario 2: Occupant preferring warm or cozy building		
Available controls	No control, partial and full control	No control, uses space heater to keep warm
	 Additional load when there is no control to their environment	

These are a few of the characteristics related to comfort. Designers, architects, and engineers can generate personas based on project requirement or conceptual design. Table 1 shows the impact of how these characteristics affect occupant behaviour. Table 1 scenario 1 shows how the window behaviour changes based on persona characteristics. If the persona's thermal preference is slightly cool and they prefer immediate comfort, the occupant will most likely open windows. If the trade-offs are *someone pays, I do not care*, and sustainable behaviour is comfort over cost. the occupants may take action that may not be energy efficient. Similarly, if the persona prefers warm or cozy and has no control in the room, they may use a space heater, adding to energy usage (see Table 1 Scenario 2).

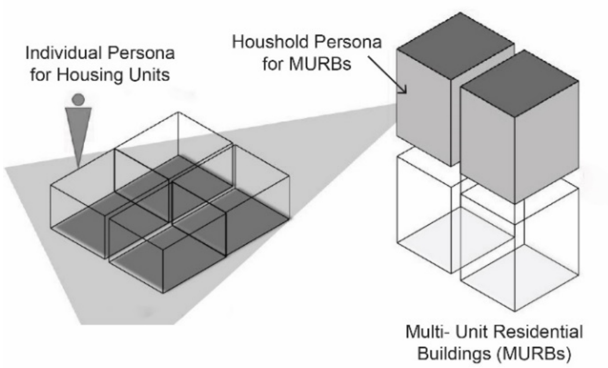


Figure 1: Personas for individual housing unit and a unit as a household persona

Occupant characteristics for an individual persona will vary in different contexts. In large buildings like multi-unit residential buildings (MURBs), it is difficult for the designers to assume who will be the occupants, the designers need to consider occupant behaviour at a unit level and at a building level. The interactive behaviour of the neighbouring units may affect the room temperature due to heat transfer. In this case, the unit can represent a household persona (see Figure 1). Individual persona and the household persona will allow the architects and designers to evaluate the buildings at micro (individual unit) and macro (household) levels. Similarly, in an academic building context, the occupant characteristics are unknown as we do not know who occupies the space. In large rooms like labs, it needs to consider a collective behaviour.

Persona as a link between design and end-users

Persona can be a link that connects design with end-users. They can be used after construction or during occupancy for building automation and energy feedback dashboards. During the design stage, the occupants' thermal preference may consider two people preferring slightly cool and one person preferring warm room temperature. During occupancy, it could be a combination of one slightly cool with two warm thermal preferences. For example, in an academic office building, all the offices may have occupants who prefer warmer temperatures. In that case, the thermostat set point will be higher than assumed, or if all the people prefer slightly cooler room temperature, then the thermostat set point will be lower. This depends on the occupancy hours, building characteristics, and other parameters mentioned in the occupant characteristics. One of this paper's arguments is that personas can be used during design, energy modelling and simulation, and building automation. During building automation, the personas can increase the granularity by collecting the user preferences from the occupants. When combined with feedback mechanisms, personas can be used as a motivation tool to make the occupants take energy-efficient actions.

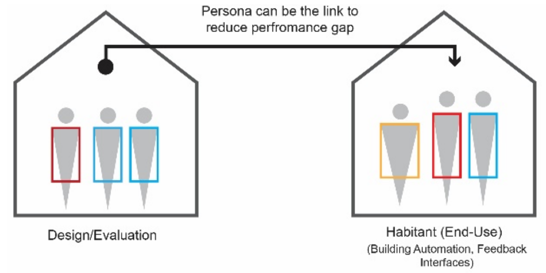


Figure 2: Persona as link. During design, the thermal preference can be two slightly cool while during occupancy it can be just right, warm, and slightly cool.

One of the key ideas was to make personas easy and accessible for designer and energy modellers to use it in design without any expert help. The goal was to design a component that will consider the number of occupants/zones and the building type (e.g., residential, or academic office) for the component to generate personas. The personas consist of two types of data: measurable data and occupant's preference data. During the design and building performance simulation, the preference and measurable data are randomly generated. The preference data includes the thermal preference, lighting preference and other parameters discussed earlier. The measured data includes the blind states, window states, lighting, room temperature, to mention a few. All these are made during the design stage, but once the building is occupied, we can collect real-time data with sensors. Likewise, the personas can be used during occupancy for building control. Measurable data is collected using sensors, and the occupants input their preferences. This may help automate the occupants' interactive behaviour, and a user interface design may help take sustainable actions.

Persona component design

A personas component was built in the Rhinocerous/Grasshopper environment using the Ladybug/Honeybee API. The Ladybug/Honeybee component is not currently integrated with an Energy Management System (EMS), but advanced modellers can use it to run the simulation manually. A zone persona component (see Figure 3) was developed using EMS, as this can be used for design analysis. Currently, the zone persona considers two occupant characteristics: thermal preference and occupancy schedules. The thermal preferences considered were warm, slightly cool, and just right. For demonstration purposes, the thermal preferences were assumed, but a literature review or a survey or a combination of both qualitative and quantitative data can develop thermal personalities in an academic context for precision. The occupant's arrival and departure were considered from monitored data for an academic-office building context. The zone persona generates a combination of thermal preferences with varying occupancy schedules automatically using EnergyPlus Runtime Language, allowing the designers to explore the what-if scenarios of occupant behaviour with ease. The case study explains the what-if scenarios for three personas.

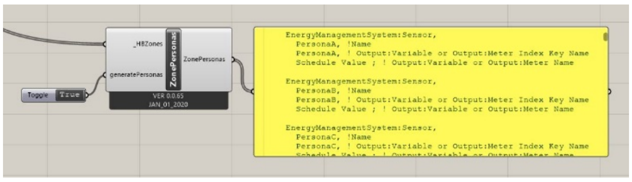


Figure 3: Screenshot of the implemented zone personas in Ladybug and Honeybee

Simulation workflow using personas

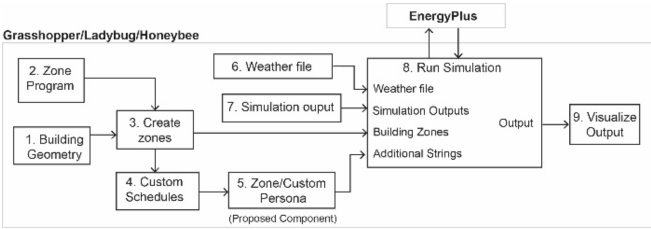


Figure 4: Simulation workflow using personas in Grasshopper/Ladybug/Honeybee

Figure 4 shows the integration of the Persona component in the Energy Analysis workflow. The component was integrated using Ladybug/honeybee and used EMS for advanced occupant modelling. The steps are:

Step 1: Building geometry is created using Rhinoceros/Grasshopper (any BIM model can be used).

Step 2: The zone programs are selected using honeybee list zone programs. These programs assume occupancy schedules based on the standards.

Step 3: Building geometry (step 1) and zone programs (step 2) are combined to create honeybee zones to run the simulation in energy plus.

Step 4: These zones are connected to create custom schedules. In this process, the custom schedule components were used to define a default schedule to override the values using EMS in step 5.

Step 5: The created occupants are passed through the proposed component zone personas or custom persona to create personas using randomness. The personas assume the settings based on thermal preferences, occupancy hours.

Step 8: The Honeybee zones (step 3), weather file (step 6), simulation outputs like zone energy usage, comfort metrics (step 7), personas (additional strings, step 5) are connected to the honeybee energy simulation component to run the simulation.

Step9: The simulation output is visualized in the Rhinoceros/Grasshopper.

Case Study: A three-box model

A three-box model was chosen to show diversity in occupant behaviour. This section describes the personas for three zones; the occupant characteristics for occupancy hours, thermal preferences, and trade-offs; numerical values based on occupant characteristics; the simulation results based on the personas; and what-if scenarios with the three types of personas.

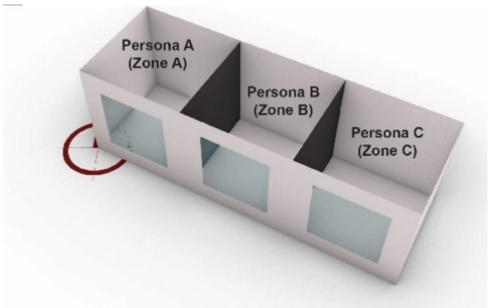


Figure 5: Three-box model

Figure 5 shows the Persona A, Persona B and Persona C applied to zone A, Zone B and Zone C. Three personas were generated for an academic context (see Figure 6). Monitored data of Canal building in Carleton university was analysed for a year for occupancy hour. The occupancy hours observed in 27 rooms reveals the occupancy pattern as morning to noon, late afternoon to the late evening, early morning to late evening depending on the occupants' position and role as researchers and professors. The monitored data were not used for gathering information to understand occupant interaction as building automation overrides the preference. For instance, if the dimming was set to 90%, the next day it was reduced to 50% and that state stays for the rest of the months. The building automation code reduces the dimming level the next day if it is greater than 50% to 50% for energy saving. Many occupants had dimming selected to 50% or 20%. Twenty percent is the lowest setting for dimming. In this setting, a few had blinds up, and a few others did not. Analysis of the monitoring data shows that building automation overrides occupancy behaviour. In this context, building automation took control, and actual behavioural pattern could not be derived. Hence, we did not consider the data from automation for occupancy behaviour.

Table 2: Persona A is a contract instructor aiming to get into a permanent academic position.

Occupancy hours	*Persona A is a morning person and prefers to work at office and often works over hours. During spring arrives to the campus at 8am and leaves around 9pm, during summer works from 6am – 7pm and in the fall works from 8am to 5pm*
Thermal Preference	*Persona A prefers a warm or cozy place and often interacts with the system to achieve the desired comfort*
Trade-offs	*Persona A prefers comfort over energy as someone else is paying the money*

Table 3: Persona B is a science professor, the time is split between classes and conducting experiments in the labs.

Occupancy hours	*Persona B arrives to the room around 2 pm in the spring as the classes are conducted in the morning and stays late for research activities. During summer works for a few hours from 7am to 2pm and during fall works from 10am to 7pm.*
Thermal Preference	*Persona B is a resident of Ottawa and prefers slightly cool room temperature. Is less interactive with the surrounding environment*
Trade-offs	*Persona B prefers comfort over energy and to achieve immediate comfort often leaves the windows open and thermostat on*

Table 4: Persona C is an experienced professor and holds position as the chair of the department. Persona C shuffles time between two locations

Occupancy hours	*Persona C uses two offices, one as a Chair and another office in his department. Persona C arrives at 2 pm and leaves at 8 pm during spring. In the summer works from 7 am – 2 pm and in the fall works from 10 am – 12 pm.*
Thermal Preference	*Persona C prefers a warm and cozy room and has seasonal allergies*
Trade-offs	*Persona C is a sustainable enthusiast and an ambassador in energy savings.*

Table 5: Persona Values for simulation

	Persona A	**Persona B**	**Persona C**
Jan - April	8am – 9pm	2pm – 8pm	2pm – 8pm
May - Aug	6am – 7pm	7am – 2pm	7am – 2pm
Sep - Dec	8am – 5pm	10am –7pm	10am-12pm
Heating set point	23°C	19°C	21°C
Cooling set point	24°C	21°C	24°C

Absence: Heating is 15° C, Cooling is 30° C

Table 5 shows the corresponding values for building performance simulation. Figure 6 shows the occupancy schedules based on the personas.

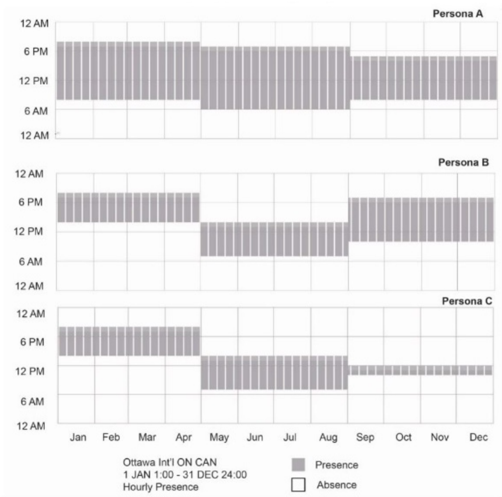


Figure 6: Persona A, B, C for academic context, considers schedules on semester basis.

Figure 7 shows the heating energy based on the persona preference. The heating energy is higher for persona A as the occupancy hours are longer than other personas, and the thermal preference is warm. Persona B and C have similar occupancy hours except for the summer, where persona B has more occupancy hours than C (Figure 6). Since persona B prefers slightly cool room temperature, the heating is lower when compared to persona C.

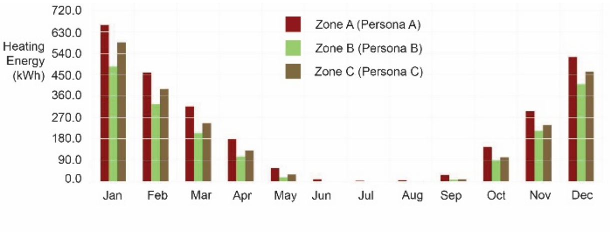


Figure 7: Heating energy for Persona A, B and C

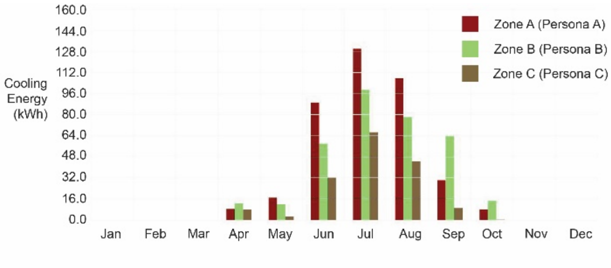


Figure 8: Cooling energy for Persona A, B and C

Figure 8 shows the cooling energy for the three-box model. The cooling energy is significantly different for all. Since persona A's occupancy hours are long, it has more cooling load than other zones. Since persona B prefers a slightly cooler room temperature, the cooling load is higher than C, which has a similar occupancy pattern to B except for summer occupancy hour.

A what-if scenario was applied to the zones to compare with multi-persona analysis. What happens if persona A occupies all the zones or if persona B occupies all the zones? A standard occupancy model of occupancy hours 9 am to 5 pm with the heating setpoint as 22 and cooling setpoint as 24 were also considered for comparison.

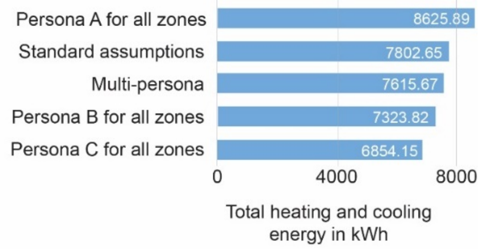


Figure 9: What-if scenario with combination of personas. Thermal load of the zones in kwh.

The various combinations were applied to the zones, and Figure 9 shows that persona A for all the zones has a higher thermal load than the standard model. Similarly, there was a significant difference between the standard model and persona C for all zones. The post-occupancy evaluation shows that the standard model either over predicts or under predicts energy usage. Personas may help in understanding this difference.

Discussion

The proposed zone personas help the designers to prototype various occupants' profiles for understanding occupant behaviour rapidly. The persona characteristics are randomly assigned from defined ranges of occupancy hours and thermal preferences. The personas allow the designers to evaluate the occupancy pattern with what-if scenarios. These scenarios may help to find the bottlenecks in the design. The personas can be used at different stages in the design; for instance, during control design, the modeller can evaluate the occupant behaviour by comparing the control options. The proposed model currently explains the persona for two occupant characteristics: occupancy hours and thermal preferences for academic office buildings. In the future, personas could integrate other occupant characteristics to see how they affects the occupants' behaviour.

The thermal preference was assumed, and occupancy hours were considered from monitored data for the case study of Canal building, from Carleton University. The thermal preference and occupancy pattern can be collected from the occupants of the same building and be compared with monitored data to validate the model. In the absence of data for new buildings, extreme conditions and typical assumptions can be used as what-if scenarios to improve the design. The data can be collected from similar buildings through surveys and participatory workshops to develop personas in the absence of information. The proposed tool currently requires programming knowledge for incorporating personas into the zone persona component. In the future, this will be minimized where the occupants can define the parameters as inputs. The tool is also designed only for an academic office building and needs a neutral approach for other building contexts that allows the end-user to define the parameters.

Conclusion

Human behaviour is complex to model as future actions, interactions of occupants are unknown and contextual. The simulation tools often overpredict or underpredict the energy consumption in buildings due to various reasons, and occupant behaviour is a primary cause. Occupant behaviour also depends on the type of technology installed in the buildings. Recent research tries to reduce the performance gap in energy buildings by understanding occupant behaviour.

Persona assumes potential occupants' behaviour based on thermal preference, lighting preference, visual preference, interactive behaviour, building context, and age. Building performance primarily revolves around the physical aspect of building design and is not user centered. In the building industry, different stakeholders have their assumptions and goals to achieve. Hence, personas can be used among various building industry stakeholders to share information and have consistent assumptions for occupant-centric design.

This paper presents personas' framework and how it can be applied at the design stage, building automation, and feedback interfaces. The persona is implemented using the most widely used visual programming environment, Grasshopper, which runs within Rhinoceros, a 3D CAD tool. Ladybug/Honeybee connects Energy Plus simulation from the Grasshopper environment. Energy Management System was used to create occupant behaviour model for personas. The study demonstrated how the usage and state of the thermostat vary based on occupant thermal preferences. The zone personas automatically create personas based on the number of zones. The designers are also able to use a custom component for defining occupant characteristics. Custom personas are useful for small projects where designers can collect information on occupant preferences like individual homes.

The persona framework is adaptable for any simulation model. In the future, all the interactive operations like windows, blinds, daylighting, and noise will be considered. Also, the model considers only occupants per zones but based on the room size, it can generate the number of occupants and consider average performance. The idea needs to be tested for feasibility and robustness.

Acknowledgement

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