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Impact of Stochastic Occupant Profiles on Commercial Energy Use in Toronto

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Abstract: *Occupants are important drivers of building energy consumption. Typical energy modelling practice is to use static occupant profiles that are deterministic in nature, applied uniformly to all rooms in a building. A novel approach to simulating dynamic occupant movement within a building is to apply unique stochastic occupancy profiles to each room in a building. These profiles consider the movement of occupants among different building spaces (e.g. offices, meeting rooms, auxiliary spaces), and can assign different movement characteristics to different occupant categories (e.g. regular workers vs. managers). This paper evaluates the impact of these stochastic occupancy schedules on the total simulated energy usage of a typical commercial office building in Toronto, Ontario. A case study that explores three occupancy simulation variations through whole building energy simulation is presented: (1) applying a static occupancy profile on the whole building, (2) using stochastic occupancy schedules unique to each room, and (3) applying a single occupancy schedule for the whole building based on averaged stochastic occupant movements. The impact on building energy use, cost, and greenhouse gas emissions is discussed.*

Keywords: *occupancy profiles, stochastic schedules, energy modelling, building performance, commercial buildings, Toronto*

INTRODUCTION

As the climate changes and building energy efficiency becomes a priority mitigation strategy, the accuracy of building energy simulations is of increasing importance. As described in Yan, et al. (2015), the "human" factor in building performance simulation, namely the effect that occupants play in the overall energy consumption of a building, is evidently important and yet inherently a source of uncertainty in predicting building energy use. Further, occupant impact in performance has become increasingly important as building envelope, mechanical systems and equipment become more and more efficient (Hoes, et al. 2009).

In this context, understanding and accurately representing occupants, and the energy driven by their behavior, presents a promising area to increase certainty in performance simulations of buildings.

Current modelling approach and limitation

In building simulation, occupants have traditionally been, and continue to be, modelled using static and deterministic schedules (O'Brien, et al. 2016). These static schedules are comprised of three 24-hour profiles – weekday, Saturday, and Sunday/holiday – applied uniformly to all rooms in a building, based on the building use type. Occupants' movements and presence in rooms further defines variables such as lighting levels and plug loads in any given room.

Implicitly, this is a simplification that enforces the premise that occupants are passive users of buildings: the static schedules disregard the dynamic nature of the interaction between occupant and building. For instance, the schedules cannot account for occupants who move from locations with extreme temperature fluctuations, or adapt to glare conditions by closing blinds and overriding automated lighting controls.

Several studies (Djunaedy, et al. 2016, Gilani, et al. 2016, Bennet and O'Brien 2017) have evaluated to appropriateness of these static occupancy assumptions and found that, when evaluated at the overall energy level, their use can lead to large discrepancies between simulated and real building performance.

State of the art – Stochastic approach

To overcome this shortcoming, alternate occupancy modelling approaches that consider occupant behaviour in a stochastic and 'agent-based' manner are being explored.

Simply put, a stochastic model attempts to reproduce occupant behaviour by creating random and non-repeating profiles for occupancy based on probabilistic models. One of the first studies to consider the probabilistic nature of occupants was Newsham, et al. (1995), which developed a stochastic model to predict lighting profiles for a typical office named Lightswitch-2002. Reinhart (2004) presents an adaptation of Newsham, et al.'s original model that includes arrival and departure events as well as temporary absences based on cumulated probability statistics.

Page, et al. (2008) proposed a generalized stochastic model for the occupant presence using Markov Chain's transition probabilities. This model predicts occupants' arrivals, departures, and breaks based on an heterogeneous

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Markov chain model (using weekly presence probability statistics). Wang, et al. (2011) developed a novel approach to modelling the movement of occupants and generate locations for each one at a given time step. This model is based on homogeneous Markov chain models.

The above models all share a statistical approach to defining occupancy, although each uses a unique algorithm or methodology. Unfortunately, these standalone models lack a common representation method to enable users to easily integrate or combine them into their studies (Chen, Hong and Luo 2017).

CASE STUDY

This paper presents a case study that compares three building energy simulation variations to determine the impact of stochastic occupant simulation: (1) applying a static occupancy profile on the whole building, (2) using stochastic occupancy schedules unique to each room, and (3) applying a single occupancy schedule for the whole building based on averaged stochastic occupant movements.

These three simulations will be evaluated based on their annual energy use, annual energy cost, and annual greenhouse gas emissions. These metrics are commonly used to assess compliance with building programs in Toronto, such as the Toronto Green Standard, Ontario Building Code, and LEED.

Simulation Tools

Occupancy Simulator

The Occupancy Simulator tool[1] is an online application led by the Lawrence Berkeley National Laboratory, based on the research of Chen, et al. (Feb 2017). This application simulates occupant movement in a building using the Markov-chain model as described in Feng, et al. (2015).

By taking high level input on occupants, spaces and events, and then simulating stochastic occupant movement, the application is able to generate occupant schedules for each space. These schedules account for dynamic movement within the building.

The Occupancy Simulator tool simulates occupant movement by relying on: Reinhart's Lightswitch-2002 model for arrivals and departure events (Reinhard 2004), Wang's homogeneous Markov chain model to describe the movement of occupants within the different office spaces (Wang, Yan and Jiang 2011), and their own stochastic model to model meeting events (Chen, Liang, et al. Feb 2017). The detailed description and implementation of these models can be found in Chen, et al. (2017).

Whole Building Simulation

Integrated Environmental Solutions' Virtual Environment ("IES-VE") suite of applications was used to develop the whole building performance simulation.[2] The IES-VE applications used include ModelIT for 3D model geometry; ApacheSim for thermal analysis; and ApacheHVAC for HVAC systems sizing and simulation. All simulations were conducted using a 10-minute time step to ensure consistency with Occupancy Simulator tool output.

Ergon

An application within the IES-VE suite, Ergon[3] was used to convert the output schedules from the Occupancy Simulator tool into occupant, lighting, and equipment schedules to be used in the VE simulation. Ergon schedules are able to maintain the ten-minute time-step output of the Occupancy Simulator tool.

Case Study Building

An archetypal commercial office building was designed for this case study. The building characteristics are listed in Table 1.

Table 1: Case Study Building Characteristics

Characteristic	Details
Gross Floor Area	5,000 m^2 (53,800 ft^2)
Stories	10 Stories
Location	Toronto, Ontario
Weather File	Toronto Pearson CWEC
Simulated Hours	8760
Holidays	Ontario Statutory Holidays, 2016
Primary Space Type	Offices (Open and Enclosed), Meeting Room
Operation	Occupied Monday to Friday, Closed Saturday and Sunday
Peak Occupants	250 People

To simplify the case study, one 500 m^2 floor plan was duplicated to create a ten-story building. The typical floor

[1] http://occupancysimulator.lbl.gov/

[2] https://www.iesve.com/software/ve-for-engineers

[3] https://www.iesve.com/software/ve-for-engineers/module/ERGON/5795

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plan and peak occupancy characteristics of the case study building are shown in Figure 1.

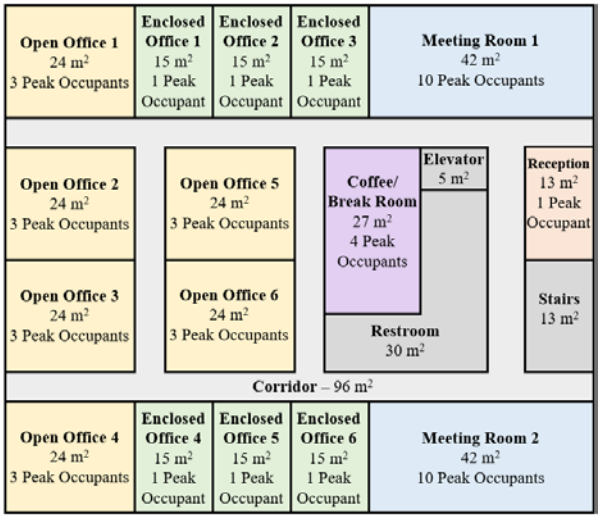

Figure 1: Typical Floor Plan

Table 2: Key Model Inputs

Characteristic	Input
Exterior Wall Performance	RSI-3.6 (R-20.2)
Roof Performance	RSI-6.2 (R-35.2)
Glazing Performance	USI-2.15 (U-0.38)
Glazing Solar Heat Gain Coefficient	0.40
Window-to-Wall Ratio	38%
HVAC Type	VAV with Reheat
Space Heating Equipment and Performance	Natural Draft Boiler: Thermal Efficiency 90%
Space Cooling Equipment and Performance	Water-Cooled Screw Chiller: COP 5.3
Air-side Heat Recovery	N/A
Outdoor Air Rates	Per ASHRAE Standard 62.1 2013
DHW Equipment and Performance	Natural Draft Heater: Thermal Efficiency 80%
DHW Fixture Flow Rates (LPM)	Per OBC: Lav. 8.35, Kitchen 8.35, Shower 9.5
Lighting Power Densities	Per SB-10 2017:
Equipment Power Densities	8.1 W/m^2 (0.75 W/ft^2)
Heating Setpoints	21°C, Setback: 18°C
Cooling Setpoints	24°C, Setback: 27°C

The floor plan was designed to be archetypal, based on the experience of the authors with commercial office layouts in the Toronto context, and assumes one tenant per floor.

The building enclosure, operations, and system characteristics meet the requirements of ASRHAE Standard 90.1-2013 as modified by the Ontario Building Code 2012 ("OBC") Supplementary Standard SB-10 2017 ("SB-10 2017") (Ministry of Municipal Affairs and Housing 2017), as described in Table 2.

Table 3 lists the typical Toronto utility rates and GHG emission factors used in this case study. The electricity utility rate was taken from Toronto Hydro[4] while natural gas rate assumes a connection to Enbridge Gas[5]. Greenhouse gas ("GHG") emission factors for electricity and natural gas are taken from SB-10 2017 (Ministry of Municipal Affairs and Housing 2017).

Table 3: Utility Rates and GHG Emission Factors

Fuel	Virtual Utility Rate	GHG Emission Factor
Electricity	$0.139/kWh	0.05 kg CO_2e/kWh
Natural Gas	$0.025/ekWh	0.189 kg CO_2e/ekWh

Simulations

Static Occupancy Simulation

The static occupancy simulation followed conventional modelling practices. The occupancy and operational profiles for lighting and equipment were assigned per ASHRAE Standard 90.1-2013 Schedule A for the office building type ("Schedule A") (ASHRAE 2013). The same static profile was applied to every room in the building. The Schedule A profiles were adjusted slightly to match the operation schedule of the case study building, which is closed on Saturday and Sunday. The Schedule A occupancy, lighting, and equipment profiles for Monday to Friday are shown in Figure 2.

[4] http://www.torontohydro.com/sites/electricsystem/business/rates/Pages/busrates.aspx

[5] https://www.enbridgegas.com/businesses/accounts-billing/gas-rates/large-volume-rates/index.aspx

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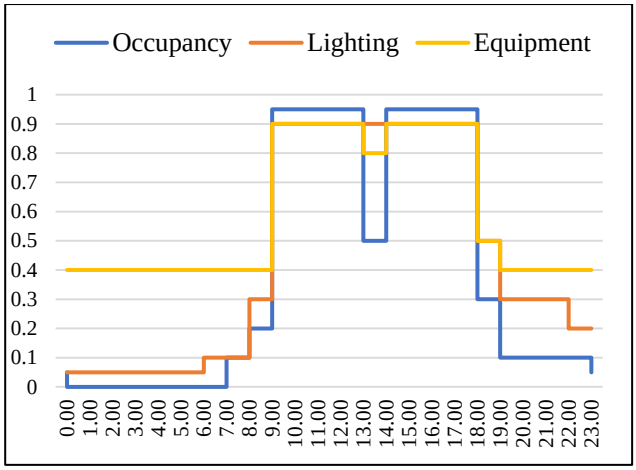

Figure 2: Schedule A Profiles

Stochastic Occupant Simulation

The stochastic occupant simulation used the Occupant Simulator and Ergon tools to create unique annual occupancy and operational schedules for each occupied room in the building. Corridors, stairs, and elevator spaces are considered to be unoccupied transient spaces. The Occupant Simulator tool is not able to generate schedules for these space-types, and it does not consider any occupant's walking time or path from one occupied space to another. For this simulation, the lighting and equipment profiles in these spaces were set to ASHRAE Standard 90.1-2013 Schedule A to avoid claiming any energy savings from these spaces.

The required inputs for the Occupant Simulator tool are described in detail by Chen, et al. (2017), but are summarized as follows.

Space Type Assumptions:

- All rooms are characterized as "office," "meeting room," or "other". The space type definition drives what occupant interactions are possible within these rooms.
- For this building, three "office" space types were defined: open office, enclosed office, and reception. The area and occupant density of these spaces was assigned per Figure 1.
- For this building, one "meeting room" space type was defined, and the typical use assumptions are listed in Table 4.
- Two "other" space types were defined for this building: the coffee/break room, and the restroom. No further assumptions are defined for this space type.

Table 4: Meeting Room Assumptions

Characteristic	Assumption
Available Meeting Days	Monday through Friday
Number of Meetings per Day	2 to 4
People per Meeting	5 to 10
Meeting Length Probability Distribution	30 Minutes: 12% 60 Minutes: 72% 90 Minutes: 12% 120 Minutes: 4%

Occupant Type & Movement Assumptions:

- Four occupant types were defined for this building: regular staff, managers, administration, and receptionist. For each "office" space type, the breakdown of occupant types is shown in Table 5.
- The movement of occupants among the building rooms is defined by assigning the proportion of time spent by each occupant type in each space type, as shown in Table 6 and the typical duration of stay by each occupant type in each space type, as shown in Table 7.
- For each occupant type, the "transition events" are defined – arrival time, leaving time, lunch time, and lunch length, as well as the possible variance from these assumptions – as shown in Table 8.

Table 5: Occupant Assignment by Space Type

Space Type	Regular Staff	Manager	Admin	Reception
Open Office	100%	0%	0%	0%
Enclosed Office	0%	84%	16%	0%
Reception	0%	0%	0%	100%

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Table 6: Proportion of Time Spent in Each Location, by Occupant Type

Occupant Location	Proportion of Time Spent			
	Regular Staff	Manager	Admin	Reception
Own Office	70%	50%	60%	80%
Other Offices	10%	5%	5%	10%
Meeting Rooms	10%	35%	25%	0%
Aux. Rooms	5%	5%	5%	5%
Outdoors	5%	5%	5%	5%

Table 7: Typical Length of Stay in Each Location, by Occupant Type

Occupant Location	Typical Length of Stay (Minutes)			
	Regular Staff	Manager	Admin	Reception
Own Office	60	60	60	60
Other Offices	20	20	20	10
Meeting Rooms	60	60	60	0
Aux. Rooms	10	10	10	10
Outdoors	20	20	20	20

Table 8: Occupant Transition Event Assumptions

Occupant Type	Arrival Time	Variance	Leaving Time	Variance	Lunch Time	Variance	Lunch Length	Variance
Regular Staff	9:00	60 min	17:00	60 min	12:00	30 min	60	15 min
Manager	9:00	60 min	17:00	60 min	12:00	30 min	60	15 min
Administration	9:00	15 min	17:00	15 min	12:00	30 min	60	15 min
Reception	9:00	0 min	17:00	0 min	12:00	30 min	30	15 min

Using these assumptions, the Occupant Simulator tool generated unique annual occupancy schedules for each room in the building, at a ten-minute time step. To include these schedules in the building energy simulation, a maximum occupancy and an accompanying variation profile needed to be developed for each room. The maximum occupancy was defined as the maximum perceived value in the annual schedule. To create the variation profile, modulating between values of 0 and 1, each ten-minute step was divided by the room's maximum occupancy.

In Figure 3 through Figure 5, the absolute occupancy generated by the Occupant Simulator tool for Enclosed Office 1, Open Office 1, and Meeting Room 1, are compared to the absolute occupancy that results from applying the ASHRAE Standard 90.1-2013 Schedule A to the peak occupancy of each room, per Figure 1. Since the Occupant Simulator occupancy varies each day, a representative day has been used in all three figures, January 12, 2016.

The annual occupancy schedules were also used to develop corresponding lighting and equipment variation profiles, based on the assumptions listed in Table 9 for weekdays. The lighting and equipment fractions during unoccupied periods were assumed to match ASHRAE Standard 90.1-2013 Schedule A. Note that on weekend days, to match Schedule A the equipment fraction is reduced to 0.30 in all space types.

Since the mechanical design of a commercial building would be based on peak occupancy, when running the building energy simulation for this case, the mechanical system sizing and outdoor air calculations were maintained from the static occupancy simulation. This has the effect of isolating the change in energy due to occupant movement, rather than allowing for changes due to different sizing in equipment or outside air.

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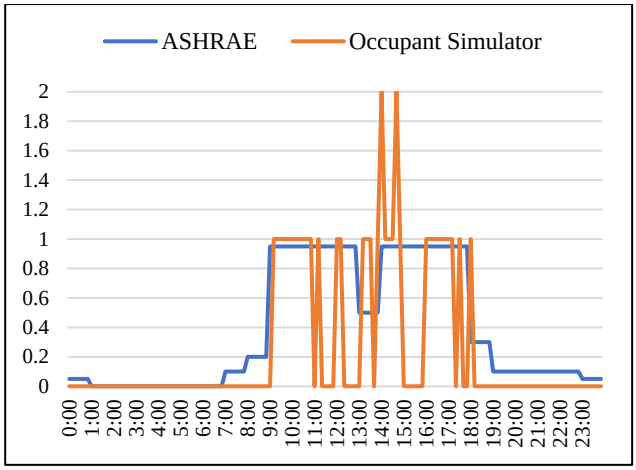

Figure 3: Absolute Occupants, Enclosed Office 1, Schedule A vs Occupant Simulator

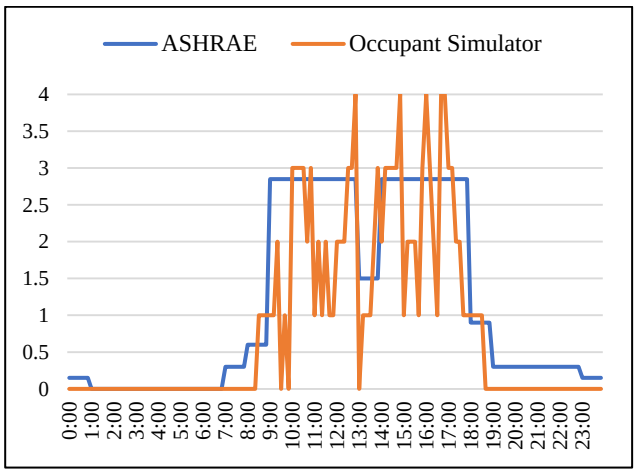

Figure 4: Absolute Occupancy, Open Office 1, Schedule A vs Occupant Simulator

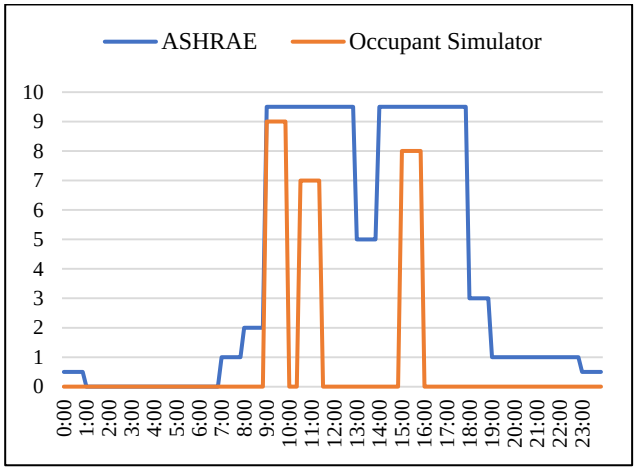

Figure 5: Absolute Occupancy, Meeting Room 1, Schedule A vs Occupant Simulator

Table 9: Lighting and Equipment Schedule Assumptions for Weekdays

Space Type	Occupancy	Lighting Fraction	Equip. Fraction
Enclosed Office	Unoccupied	0.05	0.40
	Occupied	0.90	0.90
Open Office	Unoccupied	0.05	0.40
	1 Occupant	0.30	0.60
	2 Occupants	0.60	0.80
	≥3 Occupants	0.90	0.90
Reception	09:00 to 17:00	0.90	0.90
	All Else	0.05	0.40
Meeting Room	Unoccupied	0.05	0.40
	Occupied	0.90	0.90
Washroom	Unoccupied	0.05	0.40
	Occupied	0.90	0.90
Coffee/Break Room	09:00 to 17:00	0.90	0.90
	All Else	0.05	0.40

Whole Building Average Stochastic Simulation

The whole building average stochastic simulation is a hybrid between the static occupancy and stochastic occupancy simulations. The Occupant Simulator tool output was used to determine the total occupancy of the whole building at each ten-minute time step. This schedule was converted to a whole building variation profile using the peak building occupancy, as defined in the static occupancy simulation: for each ten-minute time step, the total building occupancy was divided by the whole building peak occupancy.

Lighting and equipment fractions from the stochastic occupancy case, for all occupied rooms, were averaged to create whole building annual variation profiles for lighting and equipment.

These three annual variation profiles, for occupancy, lighting, and equipment, were then assigned to all rooms in the building energy simulation. All three profiles are shown together in Figure 6 for a representative day (January 12, 2016). As in the stochastic occupancy case, for this simulation the lighting and equipment profiles in the corridor, stairs, and elevator spaces were set to ASHRAE Standard 90.1-2013 Schedule A to avoid claiming any energy savings from these spaces.

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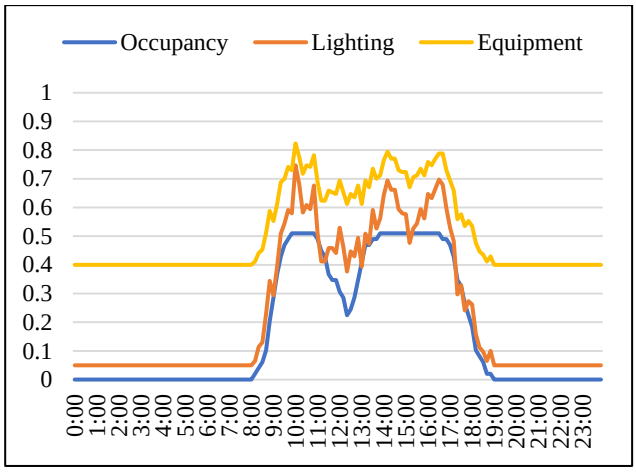

Figure 6: Whole Building Average Stochastic Profiles

The impact of this change is that while the peak occupancy of each room matches the static occupancy simulation, the whole building occupancy at each time step is based on the stochastic occupancy simulation distribution of occupants. In this way, the simulation accounts for stochastic movement of occupants among the building rooms, but input to IES-VE is simplified to a single occupancy variation profile.

As with the stochastic occupancy case, when running the building energy simulation for this case, the mechanical system sizing and outdoor air calculations were maintained from the static occupancy simulation, i.e. based on peak loads.

Results

The results of these three simulations are summarized in Table 10.

Table 10: Annual Energy, Cost, and GHG Results

Metric	Static Occupancy	Stochastic Occupancy	Whole Building Average
Annual Energy Use (kWh)	806,900	749,800	778,000
Energy Use Intensity (kWh/m^2)	161.9	150.4	156.1
Energy Reduction from Static	-	7.1%	3.6%
Annual Energy Cost	$67,500	$57,200	$58,800
Cost Reduction from Static	-	15.3%	13%
Annual GHG Emissions (kg CO_2e)	95,000	95,000	99,304
GHG Intensity (kg CO_2e/m^2	19.1	19.1	19.9
GHG Reduction from Static	-	0.0%	-4.5%

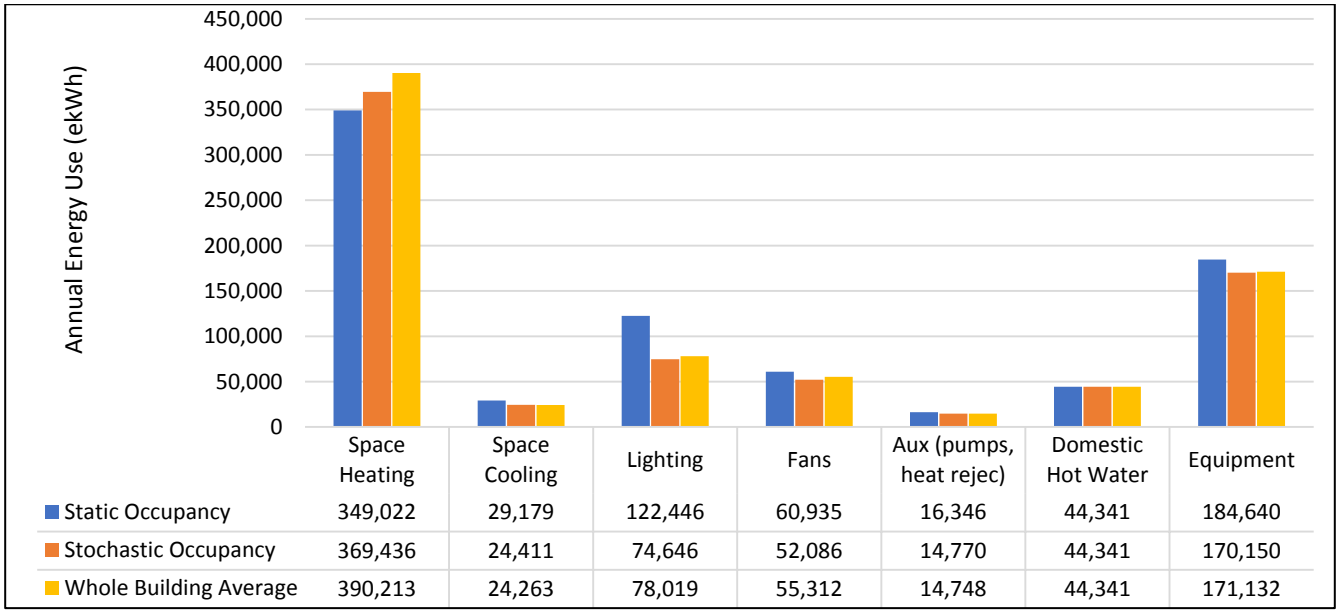

Figure 7: Annual Energy Results by End Use

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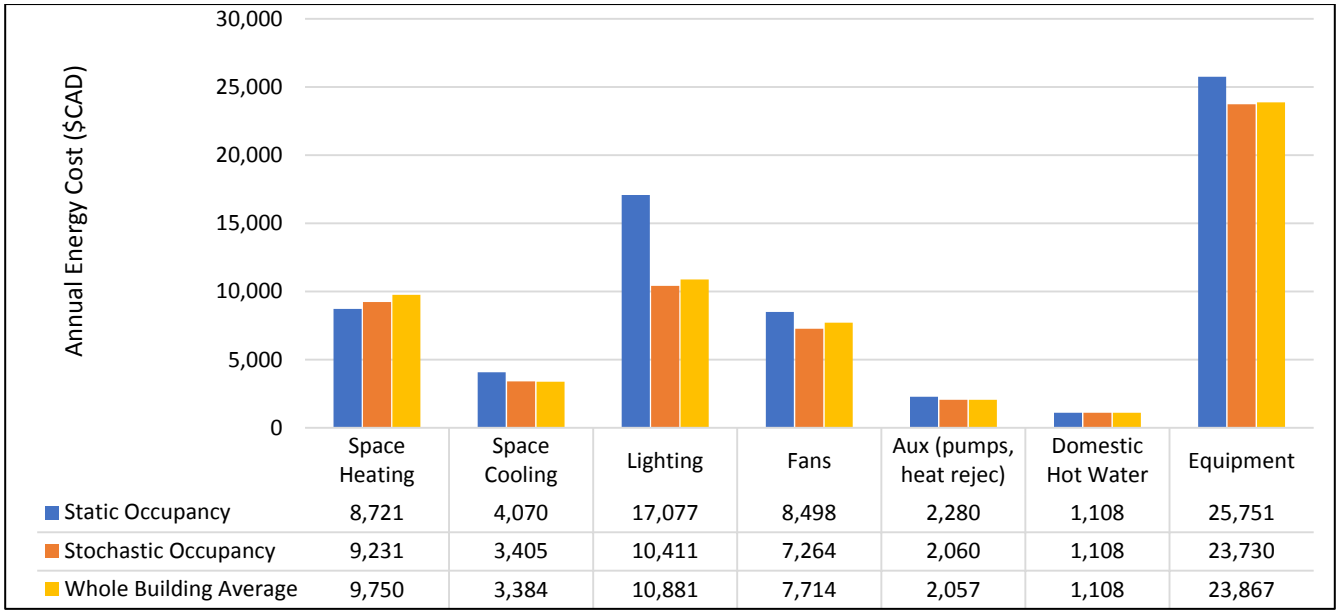

Figure 8: Annual Energy Cost Results by End Use

DISCUSSION

Implications for Program Compliance

It can be seen from these case study results that the use of stochastic occupancy profiles can have a demonstrable impact on the building energy use. By applying the Occupant Simulator variation profiles to each room individually, the annual energy use was reduced by 7.1% from the static occupancy simulation. A significant reduction occurs in both lighting and equipment energy, however there is also an increase in space heating energy to make up for the reduced internal heat gains.

The impact of this shift in energy end-use becomes apparent when considering the implicit fuel-shift from electricity for lighting and equipment, to natural gas for space heating. The disparity in Ontario's utility rates between expensive electricity and cheap natural gas boosts the annual energy cost reduction to 15.3% over the static occupancy simulation. Conversely, since Ontario's electricity grid is based on low-carbon power generation, the GHG emission factor for electricity is one-quarter that of natural gas, causing the shift in energy end-use to eliminate any reduction to GHG emissions.

These results show that, depending on the scope or purpose of the building energy simulation, and the metric being used to assess performance, differing selection of occupancy schedule can result in altered results. This is a possible concern to compliance programs, such as OBC, LEED, and the Toronto Green Standard ("TGS"), as projects could 'game' the system by applying an occupancy schedule that allows their otherwise non-compliant building to demonstrate compliance.

For programs that use a relative building performance target to demonstrate compliance (i.e. a percent-better-than reference approach), the same occupancy schedule must be applied to proposed and reference energy models, mitigating some of the concern. Further research is required to determine the full impact of using alternative occupancy schedules within this relative performance compliance method.

The TGS is among a group of compliance programs that are moving toward absolute performance targets. Given that compliance with absolute targets does not require the use of a reference building, it is important that program regulators clearly identify the occupancy schedules that must be used, to limit the potential for abuse.

Applicability in Industry

Practicality of modelling approach is a concern to the authors of this paper. Although no formal evaluation of time requirement was set up in this study, an exponential increase in individual schedules is required: 3 schedules per room (for a total of 51 unique schedules in each case study floor) compared to the typical 3 schedules for the entire floor means that both model set-up and run time are negatively affected by the stochastic methodology.

Further, even though the Occupant Simulator tool does allow the export of schedules, this feature is limited to the native EnergyPlus IDF formatting. While EnergyPlus is widely used in academia, its uptake in the modelling

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industry in Southern Ontario is less. There is no streamlined approach to importing the detailed schedules into leading industry modelling software, such as eQUEST and IES-VE. As a result, it is unlikely that the full occupant simulation approach will be integrated into current modelling practices.

The whole building average stochastic occupancy simulation of this case study was developed in an attempt to mitigate this practicality concern. Exporting only one occupancy schedule from the Occupant Simulation tool, has proven to yield results in a fraction of the time. This approach shows greater promise for integration within the current modelling industry in Ontario than the full stochastic occupant methodology.

Nevertheless, there remain drawbacks to using the Occupant Simulator tool, even to produce averaged whole-building schedules. Inherent to energy modelling are a great number of assumptions and simplifications. Stochastic occupancy introduces several additional assumptions around building operations, many of which are not known during the building design stages. In the case study presented by this paper, for instance, the assumed occupancy characteristics were compared to those obtained by the research of Bouffaron (2014), Duarte, et al. (2013), and de Bakker, et al. (2018), however these assumptions may not match the occupancy characteristics of an actual building, once it becomes operational.

Limitations of Study

The current state of the Occupant Simulator tool imposed several limitations on the case study presented by this paper (Chen, Hong and Luo 2017):

1) The simulator does not consider occupants' walking time or path from one space to another;
2) Absences from the office are applied only at the whole-building level through scheduled holidays – individual occupant absences, e.g. for vacation or illness, are not considered;
3) Occupant activity – movement, use of lighting and equipment, etc. – is driven entirely by scheduled events, and does not consider environmental factors, such as space temperature, indoor air quality, or availability of daylighting;
4) The tool is only applicable to commercial offices at this time.

The Occupant Simulator tool produces stochastic occupancy schedules – each time the simulation is run, a different annual schedule is generated. For this case study, a single simulation output was turned into an annual variation profile, for use in the building performance simulation. This has the effect of diminishing the stochastic nature of the Occupant Simulator tool. Performing multiple iterations of the case study would better fit the description of "stochastic occupancy."

Finally, this case study was performed using Toronto-specific building regulations, climate, and utility rates. The impact of occupancy schedules may vary when applied to a different context.

CONCLUSION

This paper aimed to demonstrate the importance of occupant behaviour on building energy performance. A case study was presented that explored the potential for application of stochastic occupancy profiles, as generated by the Occupant Simulator tool. The case study demonstrated that the building energy use is impacted when the dynamic movement of occupants within a building is considered, in particular showing a fuel switch as internal heat gains (primarily electricity) are reduced and space heating (by natural gas) is increased. Further research is needed to determine the full impact of these results on program compliance as well as to validate the schedules obtained from the tool when compared with real monitored buildings – a comparison study between measured and simulated occupancy, and/or measured and simulated energy, would confirm the relevance of using stochastic occupancy profiles in energy simulation.

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