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Assessing the Impact of Changes in Occupants on Design Decision Making

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Abstract: *This paper presents an assessment of the impact of the changes in occupancy and occupant behaviour schedules (i.e. lighting, plug loads, and occupancy) on the ranking of building design upgrades. The NECB medium office archetype model was used as a base model and a group of twenty design options were generated and simulated. Measured occupancy, lighting and plug loads data were used to generate three modified base models with maximum, average and minimum profiles. The same group of design options were simulated using the three modified base models. A rank list of the four occupant scenarios of design options based on their total site energy were generated and compared. The results indicated considerable change in the ranking of design options with the different occupancy, lighting and plug loads inputs.*

Keywords: *occupant behaviour, building design, BPS-aided design, design option, ranking, design decision.*

INTRODUCTION

Complying with building energy codes or upgrading the design to receive certification such as LEED, requires the building design team to demonstrate that the building has complied with a given level of energy performance. To do so, designers use building performance simulation (BPS) to create a base model of the intended building and to test the impact of energy conservation measures (ECMs) on the performance and finally to produce the optimal design option that complies with or exceeds the code or certification requirements. However, the process involves a considerable level of uncertainty due to several factors such as occupants' behaviour (OB), weather data and user assumptions. These uncertainties result in a performance gap between the actual and the simulated performance. Occupant behaviour is considered a major source of uncertainty in BPS-aided design. Occupants have a stochastic and diverse nature and their impact on building operation is significant (O'Brien & Gunay, 2015). This complicated nature of occupant behaviour makes modelling it challenging but also could be influential when it comes to performing BPS-aided design.

The current occupant modelling practice has many knowledge gaps and limitations (Yan et al., 2015). Occupants are modelled using deterministic standard schedules and power densities which indicate that occupants are present, lights are switched on, equipment and the HVAC are in operation during the typical operating hours (O'Brien et al., 2016). In addition, designers tend to use conservative assumptions to avoid under sizing HVAC (Djunaedy, Van den Wymelenberg, Acker, & Thimmana, 2011). However, when compared to reality (i.e. measured data), these assumptions can be incorrect and can possibly lead to inaccurate performance predictions and design decisions (Bennet & O'Brien, 2017; Gilani et al., 2016).

In the literature, there are a few studies on the impact of occupant behaviour during the building design process and the effectiveness of the applied ECMs. Sun and Hong (2017b) evaluated the impact of occupant related ECMs on overall building energy savings. A model of an existing office building was used for simulation. Five occupant related measures were used: lighting, plug load, comfort criteria, HVAC control, and window control. The model was tested under four different climates: Chicago (humid continental), Fairbanks (subarctic), Miami (subtropical), and San Francisco (Mediterranean) and two vintages: 1989 (representing the characteristics of existing buildings) and 2010 (representing the new constructions). Occupancy, lighting and plug loads schedules generated from site collected data were used in the simulations. The results revealed energy savings of about 22.9% when an individual ECM is used and up to 41% with multiple ECMs. Another study was conducted by Gilani et al. (Gilani et al., 2016) to understand the impact of the occupancy and occupant behaviour assumptions on the building energy use and occupants' comfort. The daylighting and energy performance of a generic perimeter office in Ottawa, Canada was evaluated. A number of design option were generated using different window and shading characteristics. The design options were simulated by using two different occupant modelling approaches: static modelling (schedules) and dynamic (the state-of-the-art occupant modelling). The study results indicated different performance predictions with the different occupant behaviour modelling approaches (Gilani et al., 2016).

Son & Hong (2017a) proposed a framework to quantify the impact of various occupants behaviours on the potential energy savings from the implementation of ECMs when

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designing and retrofitting buildings. Three occupancy styles were used in the study: austerity, normal, and wasteful. Then, a simulation workflow was introduced and implemented to a case study. The results indicated that that the impact of occupant behaviour on energy saving is much more in occupant related ECMs (i.e. ECMs that have interaction with occupants such as natural ventilation) than ECMs that has minimal interaction with occupants (Sun & Hong, 2017a).

This paper aims at identifying the impact of changes in occupancy and occupant' behaviour on the decision making and selection of energy conservation strategies during the BPS-aided building design. The following sections are organized to: first, describe the steps followed to conduct the study including the models and tools description and to present the simulation workflow. Next, the result section lists the results including authors observations. In the discussion section, the limitations of the methodology and the results are discussed, and future work recommendations are developed.

METHODS

This section describes the parametric analyses that were conducted to assess the impact of different occupancy scenarios on the ranking of design options. The section includes: the description of the base model, the simulation tool, the simulation workflow and the design options.

Description of the model

To assess the impact of changes in schedules on design decision making process, the National Energy Code of Canada for Buildings (NECB)-2015 medium office model was used. An overview of the model is shown and described in

Table 1. The energy performance of the model was evaluated by using building performance simulation (BPS) in two climates: Toronto, Ontario and Vancouver, British Colombia. Toronto climate represents the ASHRAE climate zone 6A, and Vancouver climate represents the ASHRAE climate zone 4A.

The simulation tool

OpenStudio software version 2.4.0 was used to conduct the simulation-based assessment. OpenStudio is a combination of modelling tools that performs whole-building modelling using EnergyPlus (v 8.8.0) simulation and Radiance for daylight analysis (NREL, 2017). OpenStudio Parametric Analysis Tool (PAT) allows the generation and simulation of multiple design options and outputs a report which lends itself to compare different design options.

The simulation workflow

The simulations were performed as shown Figure 4. First, design alternatives were generated the with default schedules. Records of the performance indicators were logged, and a rank list was generated using the annual Energy Use Intensity (EUI). Then, the same process was repeated using the base model with modified occupancy, lighting and equipment schedules. Three modified NECB models were generated using measured occupancy, lighting and equipment data. The occupancy data were acquired from a study conducted by Sun and Hong in (2017b) and are shown in Figure 1, while the lighting and equipment data were obtained from a study conducted on a commercial office buildings in Ottawa, Canada by Bennet and O'Brien (2017) and are shown in Figure 2 and Figure 3. Hereon, the occupancy and occupant behaviour assumptions will be referred to as "occupant assumptions".

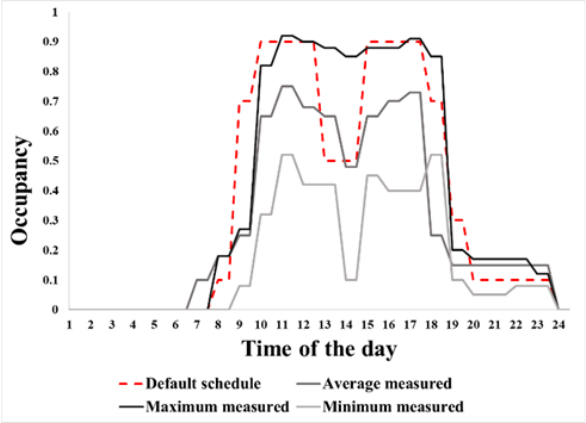

Figure 1: Occupancy schedules

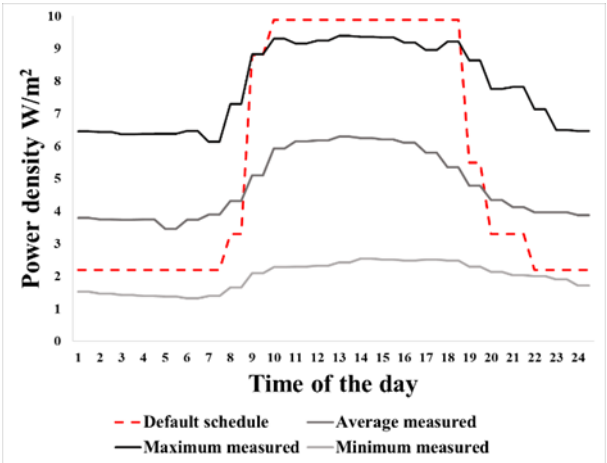

Figure 2: Equipment schedules

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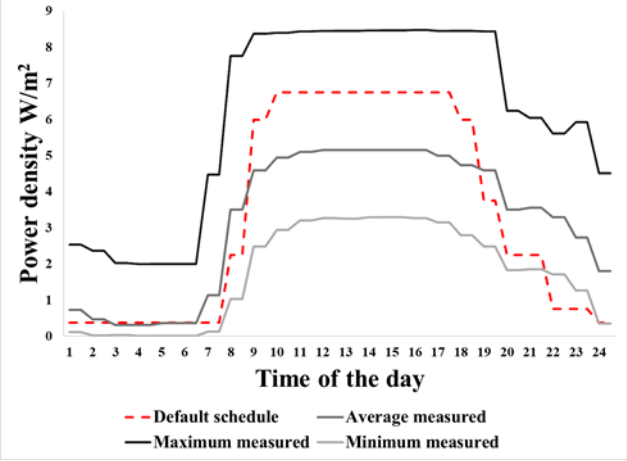


Figure 3: Lighting schedules

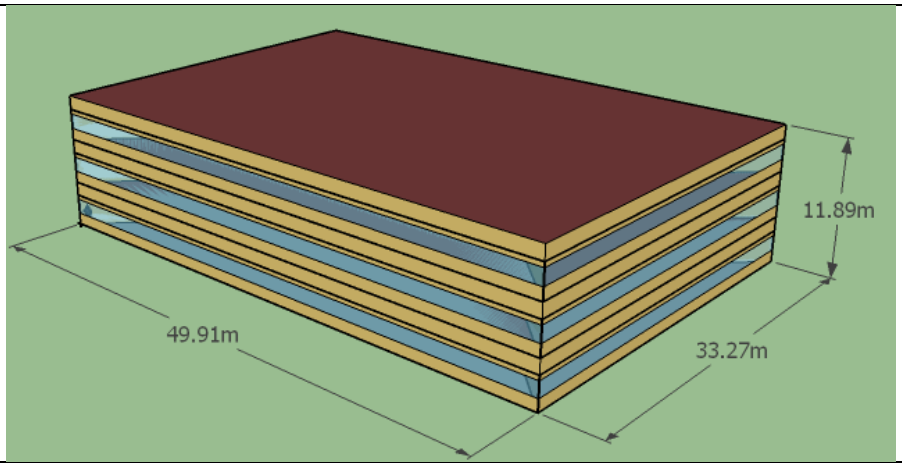
Design options

Twenty design options were generated by applying the changes shown in Table 2 to the building components and systems. The design changes were applied one at a time and no combinations of design changes were used in this study. The use of a single change at a time helps understand the sole impact of a given design modification and avoids the interactions that could incorrectly interpreted. The changes were chosen from the commonly used design improvements and ECM with the assistance of an industry practitioner. The chosen design changes included building envelope improvement such as increasing wall insulation, more efficient windows and HVAC systems improvements.

RESULTS

This section presents the results of the simulation of the twenty design options using the three-different occupant assumptions: the maximum measured loads and schedules, the average measured loads and schedules and the minimum measured loads and schedules. The results for both climates: Toronto and Vancouver are presented, to demonstrate the impact of different assumptions on building design in different contexts. Generally, the results indicate that the impact of occupants on design rank is worthy of further exploration.

Table 1: NECB-2011 Models description

Item	Description
Building type	Medium office building
Perspective	
Location	Toronto, Ontario. Vancouver, British Colombia.
Number of stories	4
Floor area	4982 $m^{2.}$
Thermal zones	18 thermal zones including (12 perimeter zones + 3 core zones+ 3 plenums).
HVAC	Single duct VAV with reheat coils and perimeter baseboard heating.

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Plant	Heating (Toronto): Primary boiler 355.6 kW thermal efficiency = 0.83 + secondary boiler 0 kW thermal efficiency = 0.85. Heating (Vancouver): Primary boiler 127.66 kW thermal efficiency = 0.83 + secondary boiler 127.66 kW thermal efficiency = 0.83. Cooling (Toronto): Primary chiller water cooled scroll 250.2 kW + cooling tower single speed. The COP of chillers = 2.5. Cooling (Vancouver): Primary chiller water cooled scroll 211 kW + cooling tower single speed. The COP of chillers = 2.5.
Setpoints	Heating = 18 ºC (night time 21:00-6:00), 20 ºC (6:00-7:00) & 22 ºC (7:00-21:00). Cooling = 35 ºC (21:00-6:00) & 24 ºC (6:00- 21:00).
Fenestration	All fixed windows. WWR = 33.01 %. Double glazing (6 mm tint glass/13 mm air gap /6 mm clear glass). U = 3.045 W/m^2 K, SHGC = 0.31
Walls	Typical insulated mass walls RSI = 2.2 K m^2/W
Roof	Typical insulated metal roof RSI = 3.52 K m^2/W

Table 2: Design options

Design Options	Default	Changes to the base model
Base	-	NECB-2011 medium office archetype
Option 01 (WI-2.64)	Wall insulation RSI = 2.2 K m^2/W	Wall insulation RSI = 2.64 K m^2/W
Option 02 (WI-3.52)		Wall insulation RSI = 3.52 K m^2/W
Option 03 (WI-4.4)		Wall insulation RSI = 4.4 K m^2/W
Option 04 (RI-5.28)	Roof insulation RSI = 3.52 K m^2/W	Roof insulation RSI = 5.28 K m^2/W
Option 05 (RI-7.04)		Roof insulation RSI = 7.04 K m^2/W
Option 06 (RI-8.81)		Roof insulation RSI = 8.81 K m^2/W
Option 07 (WWR20)	Window to wall ratio WWR = 33%	WWR = 20%
Option 08 (WWR40)		Window size WWR = 40%
Option 09 (WWR60)		Window size WWR = 60%
Option 10 (WT-01)	Window U-factor = 3.045 W/m^2 K, SHGC = 0.31	Window material U = 1.761 W/m^2 K, SHGC = 0.3
Option 11 (WT-02)		Window material U = 2.653 W/m^2 K, SHGC = 0.4
Option 12 (SH-0.4)	No shading	Shading-Overhang projection factor = 0.4
Option 13 (SH-0.6)		Shading-Overhang projection factor = 0.6
Option 14 (INFL30)	Infiltration = (I_{design}) ($F_{schedule}$) [A+B | (T_{zone}-T_{odb})|+ C(WindSpeed)+D(WindSpeed^2)]	Reduce Infiltration by 30% Infiltration= 0.7 ((I_{design}) ($F_{schedule}$) [A+B | (T_{zone}-T_{odb})|+ C(WindSpeed)+D(WindSpeed^2)])
Option 15 (BO-0.9)	Primary boiler = 0.83, secondary boiler = 0.85 (0.83 in Vancouver model)	HVAC-Boiler efficiency = 0.9
Option 16 (BO-0.95)		HVAC-Boiler efficiency = 0.95

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Option 17 (ERV)	No energy recovery	HVAC-Energy recovery ventilator
Option 18 (DCV)	Demand controlled ventilation is disabled	HVAC-Demand controlled ventilation (DCV)
Option 19 (P&F)	Various (ranges from 0.84 - 0.91)	HVAC-Increase pumps and fans efficiency = 0.96
Option 20 (CH-COP)	Chiller COP = 2.5	HVAC-Increase all chillers COP = 4

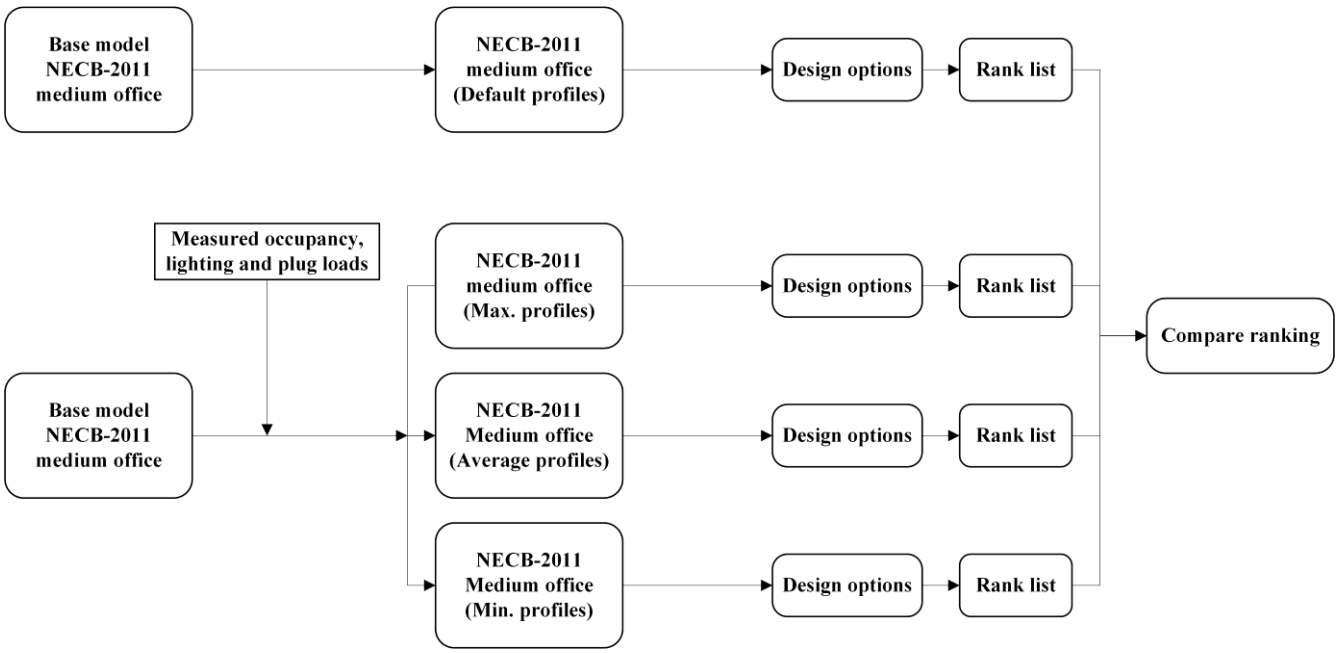

Figure 4:The simulation workflow

Sensitivity to the type of design change

Toronto

Generally, the design options ranking of the Toronto model has shown a higher number of changes in the design options ranking list when compared to the Vancouver model as shown in Figure 6 and Figure 5. The Toronto models have also shown more sensitivity to occupant assumptions in the case of design options based on envelope related changes compared to the ones based on HVAC related changes.

Design options with envelope improvements such as wall insulation, roof insulation, fixed overhang shading and reduced infiltration experienced a large number of ranking changes. The wall insulation (WI-4.4), roof insulation (RI-5.28, RI-7.04 and RI-8.81) and the exterior overhang shading (SH-0.4 and SH-0.6) moved up on the ranking list with maximum, average and minimum loads and schedules as shown in Figure 6.The increased resistance (R-value) of roof insulation and wall insulation and the reduced infiltration of the envelope mitigated the heat loss through the envelope and consequently the demand on heating and cooling is reduced. In addition, the use of external overhang shading on the south façade (SH-0.4 and SH-0.6) has moved up on the ranking list and gained more efficiency as a design change with the maximum measured loads and schedules were used. The shading has caused an increase the heat demand in the building however, it helped decreasing the cooling demand by reducing the solar gains.

On the other hand, HVAC-related design options have shown lesser sensitivity to changes in schedules and loads. This can be attributed to the cold climate (zone 6A) which reduces the impact of occupant-driven thermal loads especially with the absence of the interaction between the improved components.

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For instance, boilers' efficiency (BO-0.9 and BO-0.95) has become more effective with the average and the minimum occupant assumptions (moved up on the ranking list as shown in Figure 6). In contrast, the boiler upgrade had a relatively lower impact on the performance with the maximum occupant assumptions (moved down on ranking list as shown in Figure 6). This change in ranking can be interpreted that the decrease of internal heat gains with minimum and average occupant assumptions and the increase of internal gains in the case of maximum occupant assumptions.

Another example of the sensitivity of the design changes to occupant assumptions is the demand-controlled ventilation (DCV). The design option with DCV has become more influential and moved up on the ranking with both average and minimum occupant assumptions. The DCV is dependent on occupancy as it controls the ventilation rate according to occupancy. Hence, DCV can yield tangible energy savings when actual occupancy is modelled. In this case, the DCV reduced the amount of heating and cooling loads with the average and minimum occupancy and occupant behaviour assumptions.

Vancouver

The Vancouver based model has shown a different trend in terms of ranking design options. Generally, the design options ranking with the three occupant assumptions have experienced a lesser total number of changes compared to Toronto model. The HVAC-related design options have demonstrated lesser number of ranking changes in Vancouver model compared to Toronto model as shown in Figure 5.

On the contrary, the envelope-related design options have experienced an increased sensitivity to occupant assumptions with a larger number changes in ranking than the HVAC-related ones and the Toronto one.

For example, the demand-controlled ventilation (DCV) has become more effective with the minimum and average occupant assumptions. The DCV gained a higher ranking as a result of managing heating and cooling demands and consequently reducing the heating and cooling loads. However, the amount of energy savings was limited because the full potential of can be more noticeable with wide variety of occupancy (e.g. restaurants, retail stores) (Lawrence, 2004).

Increasing chiller COP has become more effective with the maximum occupant assumptions and moved up on the ranking. This impact can be related to the increased demand on cooling as a result of the increased heat gains from occupants, equipment and lights as show in Figure 7and Figure 8.

On the other hand, the chiller upgrade has become less influential with the minimum occupant assumptions as moved down on the ranking. This move can be related to the decrease in internal heat gains from people, lights and equipment as shown in Figure 7. This decrease reduces the demand on cooling and consequently the importance of chillers efficiency.

The window type (WT01- SHGC=0.41), that replaces the default window type (WT02- SHGC=0.31), has become more effective and moved up on the ranking. The increase in the importance rank can be interpreted as follows: with the minimum internal gains from occupancy, lighting and equipment, additional heat gains from the window become important to offset a portion of the heating loads during the heating season.

Sensitivity to the building model location

Overall, thoroughly observing the results of the simulations of the same model and the same design options in two different locations indicates variable trends. The same design options have demonstrated moderately different levels of sensitivity (34 rank changes for Toronto vs. 29 for Vancouver) in the two different locations as shown in Table 3

Generally, the HVAC-related design options of the Toronto model have shown less sensitivity to changes in occupant assumptions than the Vancouver model. While, the envelope-related design options have shown more sensitivity to the change in occupancy and occupant behaviour assumptions than the same design options in Vancouver model.

The sensitivity of the occupant assumptions

The results of the simulations have indicated that the minimum measured loads and schedules had the highest impact on the ranking of the design options. While the average and the maximum measured schedules had a lower impact on the ranking of the design options. The minimum occupancy and occupant behaviour assumptions imposes a reduction on the internal heat gains, lighting and plug loads. This decrease in casual heat gains increases the dependency on the HVAC system to offset the decrease in internal gains by injecting heat and on the envelope efficiency to mitigate heat loss.

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Design option with default loads & schedules

Rank	Design Options	EUI MJ/m2	Reduction
1	(WT-01)	507	9%
2	(WWR20)	523	6%
3	(BO-0.95)	532.56	5%
4	(CH-COP)	539.6	3%
5	(WI-4.4)	539.87	3%
6	(RI-8.81)	540.64	3%
7	(WT-02)	542.31	3%
8	(WI-3.52)	542.66	3%
9	(BO-0.9)	542.71	3%
10	(RI-7.04)	544.99	3%
11	(INFL30)	547.85	2%
12	(RI-5.28)	549.12	2%
13	(DCV)	549.29	2%
14	(WI-2.64)	549.53	2%
15	(ERV)	553.77	1%
16	(P&F)	557.57	0%
17	Base	558.98	0%
18	(SH-0.4)	561.74	0%
19	(SH-0.6)	566.07	-1%
20	(WWR40)	571.95	-2%
21	(WWR60)	618.22	-11%

Design options with maximum measured loads & schedules

Design Options	EUI MJ/m2	Reduction
(WT-01)	573.22	7%
(WWR20)	583.2	5%
(CH-COP)	594.16	3%
(RI-8.81)	596.29	3%
(BO-0.95)	597.45	3%
(WI-4.4)	597.99	3%
(WT-02)	600.11	2%
(RI-7.04)	600.13	2%
(WI-3.52)	601.82	2%
(BO-0.9)	604.3	2%
(WI-2.64)	605.47	2%
(RI-5.28)	605.66	2%
(DCV)	605.91	2%
(INFL30)	606.36	1%
(ERV)	610.52	1%
(P&F)	614	0%
Base	615.28	0%
(SH-0.4)	616.56	0%
(SH-0.6)	617.45	0%
(WWR40)	630.45	-2%
(WWR60)	674.12	-10%

Design option with default loads & schedules

Rank	Design Options	EUI MJ/m2	Reduction
1	(WT-01)	507	9%
2	(WWR20)	523	6%
3	(BO-0.95)	532.56	5%
4	(CH-COP)	539.6	3%
5	(WI-4.4)	539.87	3%
6	(RI-8.81)	540.64	3%
7	(WT-02)	542.31	3%
8	(WI-3.52)	542.66	3%
9	(BO-0.9)	542.71	3%
10	(RI-7.04)	544.99	3%
11	(INFL30)	547.85	2%
12	(RI-5.28)	549.12	2%
13	(DCV)	549.29	2%
14	(WI-2.64)	549.53	2%
15	(ERV)	553.77	1%
16	(P&F)	557.57	0%
17	Base	558.98	0%
18	(SH-0.4)	561.74	0%
19	(SH-0.6)	566.07	-1%
20	(WWR40)	571.95	-2%
21	(WWR60)	618.22	-11%

Design options with average measured loads & schedules

Design Options	EUI MJ/m2	Reduction
(WT-01)	469.63	10%
(WWR20)	491.9	6%
(BO-0.95)	496.65	5%
(WI-4.4)	505.32	3%
(CH-COP)	506.18	3%
(RI-8.81)	506.48	3%
(BO-0.9)	506.81	3%
(DCV)	509.39	3%
(RI-7.04)	510.23	2%
(WI-3.52)	510.51	2%
(WT-02)	510.64	2%
(RI-5.28)	515.69	1%
(WI-2.64)	515.91	1%
(INFL30)	516.12	1%
(ERV)	518.16	1%
(P&F)	521.67	0%
Base	523.1	0%
(SH-0.4)	526.86	-1%
(SH-0.6)	528.94	-1%
(WWR40)	537.3	-3%
(WWR60)	585.12	-12%

Design option with default loads & schedules

Rank	Design Options	EUI MJ/m2	Reduction
1	(WT-01)	507	9%
2	(WWR20)	523	6%
3	(BO-0.95)	532.56	5%
4	(CH-COP)	539.6	3%
5	(WI-4.4)	539.87	3%
6	(RI-8.81)	540.64	3%
7	(WT-02)	542.31	3%
8	(WI-3.52)	542.66	3%
9	(BO-0.9)	542.71	3%
10	(RI-7.04)	544.99	3%
11	(INFL30)	547.85	2%
12	(RI-5.28)	549.12	2%
13	(DCV)	549.29	2%
14	(WI-2.64)	549.53	2%
15	(ERV)	553.77	1%
16	(P&F)	557.57	0%
17	Base	558.98	0%
18	(SH-0.4)	561.74	0%
19	(SH-0.6)	566.07	-1%
20	(WWR40)	571.95	-2%
21	(WWR60)	618.22	-11%

Design options with minimum measured loads & schedules

Design Options	EUI MJ/m2	Reduction
(WT-01)	422.05	11%
(BO-0.95)	438.55	7%
(BO-0.9)	452	5%
(DCV)	453.88	4%
(RI-8.81)	455.06	4%
(RI-7.04)	458.04	3%
(CH-COP)	458.71	3%
(WWR20)	458.73	3%
(WI-4.4)	460.6	3%
(RI-5.28)	462.34	2%
(WT-02)	462.9	2%
(INFL30)	462.95	2%
(WI-3.52)	463.25	2%
(ERV)	467.91	1%
(WI-2.64)	468.47	1%
(P&F)	472.14	0%
Base	473.54	0%
(SH-0.4)	484.35	-2%
(WWR40)	486.67	-3%
(SH-0.6)	489.13	-3%
(WWR60)	527.76	-11%

Figure 6:Toronto model simulation results

Design options with default loads and schedules

Rank	Design options	EUI MJ/m2	Reduction
1	(WT-01)	437.9	7%
2	(WWR20)	447.02	5%
3	(BO-0.95)	454.05	4%
4	(RI-8.81)	457.96	3%
5	(WI-4.4)	459.76	3%
6	(CH-COP)	460.24	3%
7	(RI-7.04)	460.57	3%
8	(BO-0.9)	461.27	2%
9	(WI-3.52)	462.19	2%
10	(WT-02)	463.74	2%
11	(RI-5.28)	464.7	2%
12	(WI-2.64)	466	1%
13	(INFL30)	468.95	1%
14	(SH-0.6)	471.24	0%
15	(P&F)	471.85	0%
16	(SH-0.4)	471.91	0%
17	(DCV)	471.92	0%
18	(ERV)	472.34	0%
19	Base	472.83	0%
20	(WWR40)	486.46	-3%
21	(WWR60)	527.68	-12%

Design options with maximum measured loads and schedules

Design options	EUI MJ/m2	Reduction
(WT-01)	507.87	5%
(WWR20)	509.5	5%
(CH-COP)	519.96	3%
(BO-0.95)	522.55	2%
(RI-8.81)	522.8	2%
(WI-4.4)	523.66	2%
(RI-7.04)	524.68	2%
(WI-3.52)	525.47	2%
(BO-0.9)	526.79	1%
(WT-02)	527.17	1%
(RI-5.28)	527.63	1%
(SH-0.6)	528.31	1%
(WI-2.64)	528.45	1%
(SH-0.4)	529.87	1%
(INFL30)	530.78	1%
(P&F)	532.72	0%
(DCV)	532.73	0%
(ERV)	533.25	0%
Base	533.59	0%
(WWR40)	546.42	-2%
(WWR60)	585.29	-10%

Design options with default loads and schedules

Rank	Design options	EUI MJ/m2	Reduction
1	(WT-01)	437.9	7%
2	(WWR20)	447.02	5%
3	(BO-0.95)	454.05	4%
4	(RI-8.81)	457.96	3%
5	(WI-4.4)	459.76	3%
6	(CH-COP)	460.24	3%
7	(RI-7.04)	460.57	3%
8	(BO-0.9)	461.27	2%
9	(WI-3.52)	462.19	2%
10	(WT-02)	463.74	2%
11	(RI-5.28)	464.7	2%
12	(WI-2.64)	466	1%
13	(INFL30)	468.95	1%
14	(SH-0.6)	471.24	0%
15	(P&F)	471.85	0%
16	(SH-0.4)	471.91	0%
17	(DCV)	471.92	0%
18	(ERV)	472.34	0%
19	Base	472.83	0%
20	(WWR40)	486.46	-3%
21	(WWR60)	527.68	-12%

Design options with average measured loads and schedules

Design options	EUI MJ/m2	Reduction
(WT-01)	396.33	8%
(WWR20)	407.86	6%
(BO-0.95)	414.92	4%
(RI-8.81)	419.43	3%
(WI-4.4)	420.03	3%
(BO-0.9)	421.91	3%
(RI-7.04)	422.01	3%
(CH-COP)	422.2	3%
(WI-3.52)	422.6	2%
(WT-02)	423.58	2%
(RI-5.28)	426.05	2%
(WI-2.64)	426.51	2%
(INFL30)	429.55	1%
(SH-0.6)	430.22	1%
(SH-0.4)	430.76	1%
(DCV)	431.02	0%
(P&F)	432.11	0%
(ERV)	432.65	0%
Base	433.1	0%
(WWR40)	446.54	-3%
(WWR60)	484.51	-12%

Design options with default loads and schedules

Rank	Design options	EUI MJ/m2	Reduction
1	(WT-01)	437.9	7%
2	(WWR20)	447.02	5%
3	(BO-0.95)	454.05	4%
4	(RI-8.81)	457.96	3%
5	(WI-4.4)	459.76	3%
6	(CH-COP)	460.24	3%
7	(RI-7.04)	460.57	3%
8	(BO-0.9)	461.27	2%
9	(WI-3.52)	462.19	2%
10	(WT-02)	463.74	2%
11	(RI-5.28)	464.7	2%
12	(WI-2.64)	466	1%
13	(INFL30)	468.95	1%
14	(SH-0.6)	471.24	0%
15	(P&F)	471.85	0%
16	(SH-0.4)	471.91	0%
17	(DCV)	471.92	0%
18	(ERV)	472.34	0%
19	Base	472.83	0%
20	(WWR40)	486.46	-3%
21	(WWR60)	527.68	-12%

Design options with minimum measured loads and schedules

Design options	EUI MJ/m2	Reduction
(WT-01)	334.24	13%
(WWR20)	355.09	7%
(BO-0.95)	356.34	7%
(WI-4.4)	363.3	5%
(RI-8.81)	364.42	5%
(BO-0.9)	366.39	4%
(WI-3.52)	366.96	4%
(WT-02)	367.07	4%
(RI-7.04)	367.24	4%
(RI-5.28)	372.36	3%
(WI-2.64)	372.66	3%
(CH-COP)	373.43	2%
(INFL30)	375.86	2%
(DCV)	379.2	1%
(P&F)	381.45	0%
(ERV)	381.92	0%
Base	382.49	0%
(SH-0.4)	384.9	-1%
(SH-0.6)	388.47	-2%
(WWR40)	394.34	-3%
(WWR60)	424.28	-11%

Figure 5: Vancouver model simulation results

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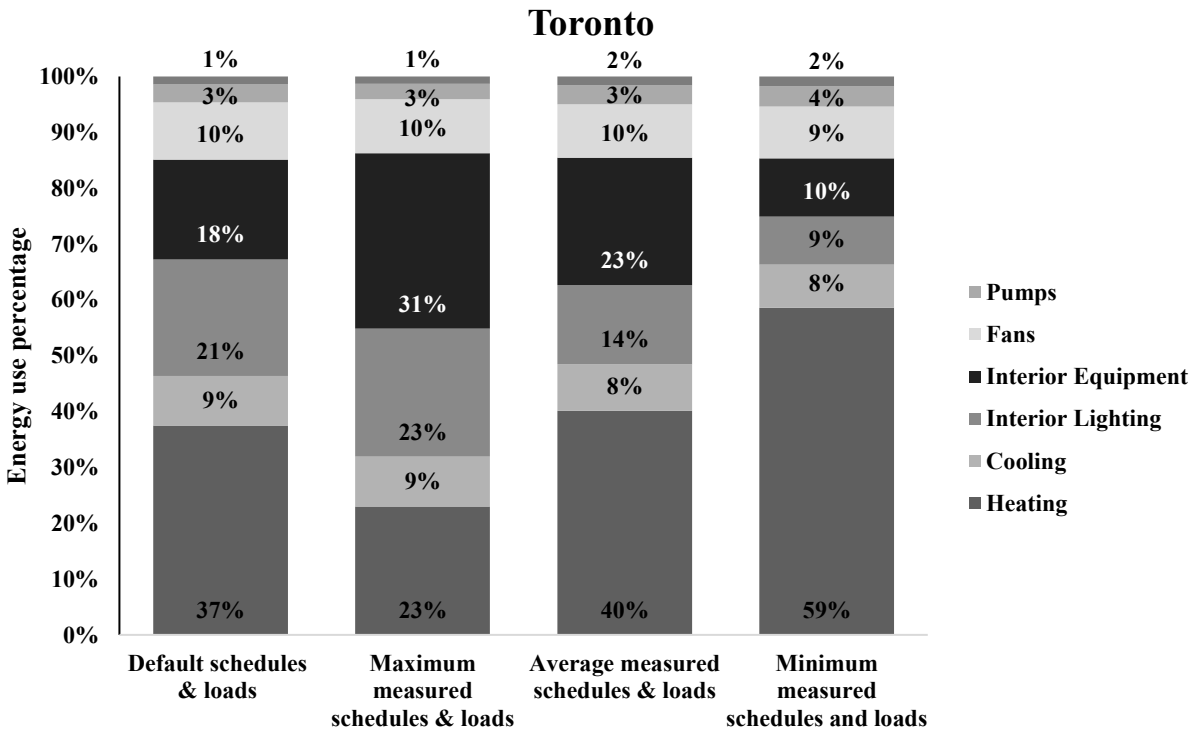

Figure 7: Toronto medium office model energy end use by category

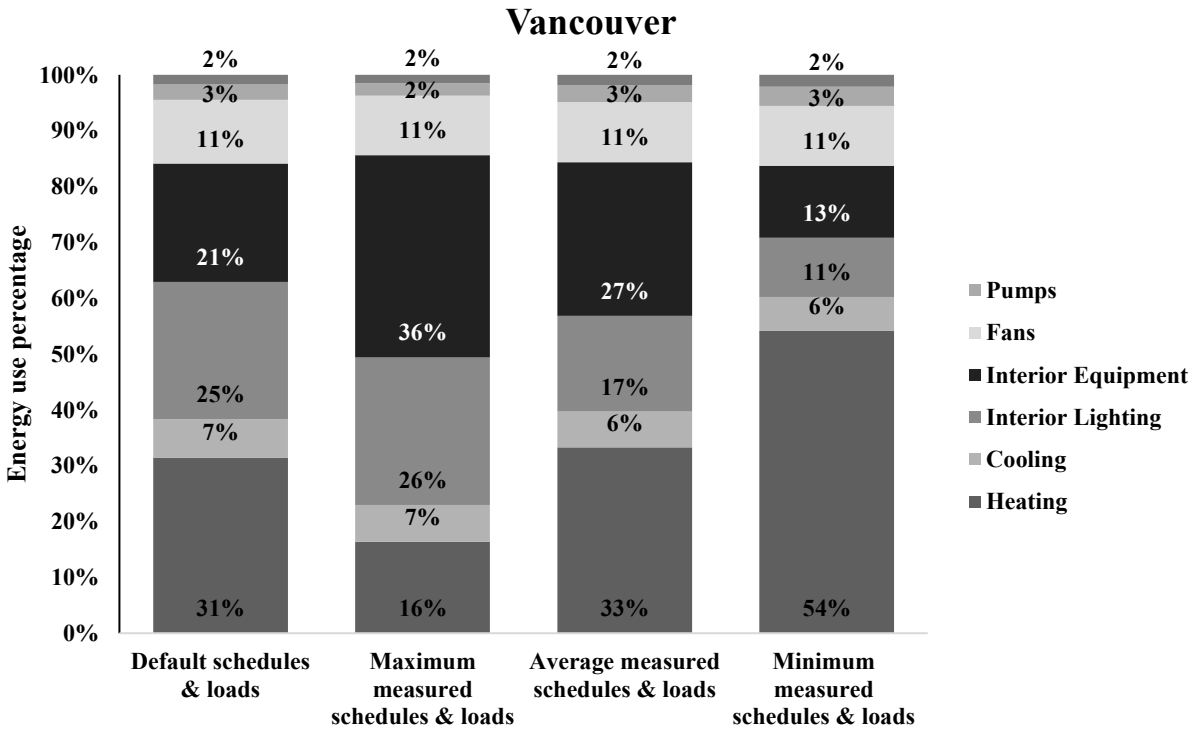

Figure 8: Vancouver medium office model energy end use by category

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Table 3: Changes in ranking with different occupant assumptions

		No. of changes with max. occupant assumptions	No. of changes with average occupant assumptions	No. of changes with min. occupant assumptions
Toronto	HVAC	3	3	5
	Envelope	6	6	11
Vancouver	HVAC	4	4	5
	Envelope	7	1	8

DISCUSSION

This study examined the impact of different occupancy and occupant behaviour assumptions on the office buildings design decision making process. The main goal was to make a case to promote further research and garner the attention of researchers, policy makers and practitioners to the sensitivity of the design process to occupancy and occupant behaviour.

The results of the simulations of the twenty-one design options indicated variable sensitivity of design options ranking to the type of design changes (i.e. HVAC-related changes, or envelope-related changes) used and to the climate. Based on the study results, it can be generally concluded that in cold climates (i.e. Toronto), the design options based on HVAC-related changes are less sensitive to changes in occupancy and occupant behaviour assumptions than the envelope ones. Furthermore, in the mixed humid climate (e.g. Vancouver) design options based on envelope-based changes demonstrated less sensitivity to the change in occupancy and occupant behaviour assumptions than the HVAC ones. Despite, the fact that simulation results in both climates indicated that design options were sensitive to occupancy and occupant behaviour assumption, the Toronto model has experienced more ranking changes specially with design option with envelope-related changes than the Vancouver model.

These findings can be used to guide building designers and modellers who would like to make robust design decisions by avoiding the use of design changes that indicate high sensitivity to occupancy and occupant behaviour assumptions and can be associated with a high level of uncertainty.

On another front, the building models in the two climates, the humid cold and the mixed humid experienced a noticeable ranking change with the different occupant assumptions. This demonstrates the need to properly model occupants and occupant behaviour despite the different climatic contexts.

Furthermore, designers/modellers should pay more attention to understand the occupancy and operation patterns in buildings in order to produce an accurate building model and make the right design decision. For instance, they need to specify the type of schedules: default, averaged (based on similar cases), extremes (maximum or minimum based on similar cases) when producing a building energy model.

Finally, some changes on the ranking lists might appear minimal or has minor differences when compared to the based case. This is because design changes, in this study, were used one at a time and were not compiled and therefore, performance-based interactions between building systems and subsystems with a group of design upgrades are not considered here (O 'Brien, Athienitis, Kesik, Eng, & Kesik, 2011). In addition, designers, in some cases, are looking for some minor changes that can enable them meet code or certification requirements.

This study had several limitations:

(1) The study was conducted on one building type and size (NECB-2015 medium office building).
(2) The design options were generated using selected design changes and were using one at a time.
(3) The design changes were selected to be based on non-adaptive behaviour of occupants (e.g. no operable windows or automated shading).
(4) The design options were simulated only in two different climates.
(5) (The analysis scope did not cover all possible factors that can affect the building performance and the ranking of design options such as building vacancies.

Hence, further research is required considering different building types (commercial, residential, etc.) and investigate more building sizes (e.g. small offices, large offices) in different climates. Design options with combined ECMs should also be assessed to verify the impact of occupancy and occupant behaviour assumptions on this kind of design options.

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Finally, applying the research findings to real case study is required to evaluate the magnitude of impact in a real design process. This would demonstrate the actual impact of using informed occupancy and occupant behaviour assumptions and would lead to a more educated design decision making.

CONCLUSION

This paper examined the impact of changes in occupant modelling assumptions on the ranking of design options. The study included simulation of a number of design options generated using common design changes and ECMs and the simulation took place in two different climates: Toronto (ASHRAE climate zone 6A) and Vancouver (ASHRAE climate zone 4A).

The results indicated variable impact of occupancy and occupant behaviour schedules and assumptions. The research outcomes also demonstrated the sensitivity of the different ECMs to these assumptions. The study also illustrated that occupancy and occupant behaviour had a varying role in relation to the climatic conditions.

The objective of this paper was to demonstrate that appropriate modelling of occupancy and occupant behaviour is important for building design process and decision making. Recommendations were developed to further investigate the impact of different schedules on a larger number of design options where combinations of ECMs are also studied. Furthermore, the impact of different occupant assumptions needs to be verified with different building types, sizes, and climates.

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REFERENCES

Bennet, I. E., & O'Brien, W. (2017). Office building plug and light loads: Comparison of a multi-tenant office tower to conventional assumptions. *Energy and Buildings*, *153*, 461–475. https://doi.org/10.1016/j.enbuild.2017.08.050

Djunaedy, E., Van den Wymelenberg, K., Acker, B., & Thimmana, H. (2011). Oversizing of HVAC system: signatures and penalties. *Energy and Buildings*, *43*(2), 468–475.

Gilani, S., O'Brien, W., Gunay, H. B., Juan Sebastián Carrizo, Gilani, S., O'Brien, W., … Carrizo, J. S. (2016). Use of dynamic occupant behavior models in the building design and code compliance processes. *Energy and Buildings*, *117*(November), 260–271. https://doi.org/10.1016/j.enbuild.2015.10.044

Lawrence, T. (2004). Demand-Controlled Ventilation and Sustainability. *ASHRAE Journal* , *46*(12), 120–121. Retrieved from https://search.proquest.com/openview/0539e9c3778737998dfdcc03ce2e8910/1?pq-origsite=gscholar&cbl=41118

NREL. (2017). OpenStudio | OpenStudio. Retrieved November 13, 2017, from https://www.openstudio.net/

O'Brien, W., Gaetani, I., Gilani, S., Carlucci, S., Hoes, P.-J., & Hensen, J. (2016). International survey on current occupant modelling approaches in building performance simulation. *Journal of Building Performance Simulation*, *10*(5–6), 653–671. https://doi.org/10.1080/19401493.2016.1243731

O'Brien, W., & Gunay, H. B. (2015). Mitigating office performance uncertainty of occupant use of window blinds and lighting using robust design. In *Building Simulation* (Vol. 8, pp. 621–636). Tsinghua University Press.

O 'Brien, W., Athienitis, A., Kesik, T., Eng, P., & Kesik, T. (2011). Parametric Analysis to Support the Integrated Design and Performance Modeling of Net-Zero Energy Houses. *ASHRAE Transactions*.

Sun, K., & Hong, T. (2017a). A Framework for Quantifying the Impact of Occupant Behavior on Energy Savings of Energy Conservation Measures A Framework for Quantifying the Impact of Occupant Behavior on Energy Savings of Energy Conservation Measures. *Energy and Buildings*, *146*, 383–396.

Sun, K., & Hong, T. (2017b). A simulation approach to estimate energy savings potential of occupant behavior measures. *Energy and Buildings*, *136*, 43–62.

Yan, D., O'Brien, W., Hong, T., Feng, X., Gunay, H. B., Tahmasebi, F., … Mahdavi, A. (2015). Occupant behavior modeling for building performance simulation: Current state and future challenges. *Energy and Buildings*, *107*, 264–278. https://doi.org/10.1016/j.enbuild.2015.08.032