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Energy efficiency measures for net-zero energy ready building codes

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Abstract: *In Canada, the National Energy Code for Buildings (NECB) is widely adopted by provinces for construction of new 'Part 3' buildings. The Pan-Canadian Framework on Clean Growth and Climate Change released in 2016 included an action for net-zero energy ready (nZER) building codes by 2030. Previously, the Standing Committee on Energy Efficiency in Buildings had considered energy efficiency measures the future building codes could incorporate to attain nZER. Energy simulations of these measures were performed using mainly Can-Quest software in six climate zones. The Large Office archetype modelled is ten storeys with a total floor area of 13,380 m2. The measures are grouped into tiers to align with the development of potential requirements for future 2020, 2025 and 2030 editions of the NECB. Excluding the impact of cross-effects, energy savings of different measures could provide 50% savings relative to the NECB 2015. The work highlights potential savings and current modelling limitations.*

Keywords: *Building energy modelling, Energy efficiency measures, Can-Quest, Energy simulation, National Energy Code for Buildings, net-zero energy ready (nZER) building*

INTRODUCTION

The Pan-Canadian Framework on Clean Growth and Climate Change announced in December 2016 included an action to make new building more energy efficient with a goal of adoption by the provinces of a more stringent energy code, i.e. net-zero energy ready (NZER) model building code by 2030. Also in the fall of 2016, the Canadian Commission on Building and Fire Codes approved a long-term energy strategy. Accordingly, in 2017 the Standing Committee on Energy Efficiency in Buildings (SC-EEB) set the direction for a tiered approach for the National Energy Code of Canada for Buildings (NECB). This direction seeks to explore the concept of a building target energy consumption that decreases linearly by 12.5% during each code cycle to reach the NZER by 2030. Previously SC-EEB during their sixth meeting held in February 2016, discussed some building energy efficiency measures for possible implementation. Those measures are the focus of this work.

In Canada, the National Energy Code for Buildings (NECB) is widely adopted by provinces for construction of new 'Part 3' buildings (National Research Council, 2018). The Code sets minimum requirements for construction of new commercial and institutional buildings. In Canada, building code adoption is a provincial responsibility. The adopted code requirements become the 'worst' building that can be built. Therefore, rather than focus on leading-edge design for a specific site or building, code development work investigates options for increasing the default minimum for all buildings. Individual measures considered beneficial for broad application are then analysed to ensure they do not contradict other code objectives, are practical and enforceable. Changes sufficiently developed are presented by the Commission on Building and Fire Codes for the public in the fall every year.

The present work aims to quantify through "screening-level" modelling if the measures reach the NZER target and provide a high-level view of whether the improvement will trend along the linearly decrease envisioned. The desired contribution of the assessment is to help SC-EEB make informed decisions on the proposed measures and identifying future research needs. The present work focuses on an archetype large office and modelling is done using Can-Quest (Version 1.1) software.

METHODOLOGY

Simulations performed for the NECB archetypes large office in six locations/climate zones of Canada:

- Victoria (Zone 4)
- Windsor (Zone 5)
- Montréal (Zone 6)
- Edmonton (Zone 7a)
- Fort McMurray (Zone 7b)
- Yellowknife (Zone 8)

The energy simulations baseline is established as per the procedures outlined in building energy performance path of NECB 2015 for the reference building.

Establishing the baseline involved setting up the Can-Quest input parameters as per Part 8 using the corresponding prescriptive requirements of NECB 2015, where

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applicable.[1] Changes were then made to the baseline models by including energy efficiency measures.

The energy efficiency measures are modelled individually to identify the percentage savings in overall energy consumption. The combined savings as per different tiers is approximated by summing up the savings of individual measures without taking into consideration the interactions between them (except tier 1).

Table 1 Can-Quest input parameters

Simulation Parameters	Source
Overall thermal transmittance (U-Value) of building envelope	NECB 2015 Part 3
Fenestration and doors to wall ratio (FDWR)	NECB 2015 Part 3
Air infiltration rates	NECB 2015 Part 3
Lighting power densities	NECB 2015 Part 4
Heating, ventilating and air-conditioning (HVAC) system	NECB 2015 Part 5
Service water system	NECB 2015 Part 6
Operational schedules	NECB 2015 Part 8

This simplification of the combined savings is expected to result in overestimation of individual effects. The resulting percentage savings in overall energy consumption relative to the NECB 2015 baseline are considered with the SC-EEB desired direction.

Cross-effects can be significant and reporting of NECB savings from one edition to the next include cross-effects. However, for this development work incorporation of cross-effects is premature given the ambiguity related to the specific of the measures. This work to aid in prioritization of single measures to which specificity can be applied and, where necessary a modelling procedure developed.

Can-Quest input parameters for NECB 2015 compliant baseline simulation are summarised in Table 1. Results of the simulations conducted using Can-Quest building energy simulation software are presented. These simulations are performed for NECB representative buildings called ‘archetypes’ which SC-EEB assessed to represent the most common buildings being built in Canada.

BENCHMARKING OF SIMULATIONS

Although this work focuses on changes to a code compliant building, for this study benchmarking the simulation to previous work was important. Results of the NECB 2015 compliant simulations are compared against the previous study conducted by Arborus consulting (Knapp, 2017) for the archetypes including large office, a large multi-use residential building (MURB) and big box store. Given the incremental nature, it is important to consider these differences. The purpose of the comparison is to identify gaps and demonstrate the repeatability of results. A comparison of the results between the two studies is presented in Table 2.

Table 2 Benchmarking of results

Archetype	Average NECB 2015 baseline energy consumption (ekWh)		Difference (%)
	Arborus consulting	Present work	
Large office	2,107,424	1,794,303	-14.9%
Large MURB	2,414,888	2,564,106	6.2%
Bix Box Store	1,810,038	1,633,643	-9.8%

It is observed that the overall energy consumption of the three archetypes in equivalent kilowatt hour (ekWh) averaged out for different climate zone in both studies varies by up to a difference of 15%. These differences in results are attributed to the dissimilarity in certain input parameters such as:

- The reference study is based on the building envelope air infiltration rates less than that prescribed by NECB 2015.
- In reference study, the lighting power is modelled on a space by space basis using an assumed mix of space types in each archetype.

Previously as part of the building Energy Use Intensity (EUI) development work for the NECB which was not recommended for public review, SC-EEB examined variability in modeling results when using different software (Footprint, 2014). The study noted an additional one influence explaining differences in modeling results is user preference and modelling style[2]. Since the purpose of

[1] The CanQuest reference building at the time of this investigation is based on the NECB 2011.

[2] Modeler preference is an interesting topic of study but beyond the scope of the current work.

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the present analysis is to model the archetypes as per NECB 2015 and quantify the effect of the energy efficiency measures based on the same, tailoring the results with the previously conducted simulations was not required.

DESCRIPTION OF NECB ARCHETYPES

Large Office

The large office has 10 above grade storeys with a total floor area of 13,380 square metres. Each storey of the large office is divided into a core and a perimeter zone. The large office HVAC system is modelled as a central Variable Air Volume (VAV) air handling system. Heating is provided by hot water coils connected to a natural gas-fired boiler and cooling is provided by chilled water coils connected to a chiller which rejects heat to a cooling tower. Hydronic baseboard heating is also provided as required by NECB 2015.

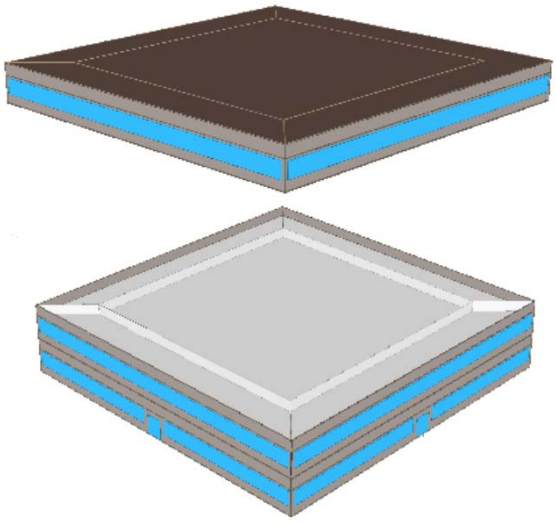

Figure 1 NECB Archetype Large Office

Large MURB

The large MURB has 10 above grade and 2 below grade storeys with a total floor area of 13,613 square metres. It has a constant volume HVAC system. Heating is provided by natural gas fired water boiler while cooling is provided by Air-cooled direct-expansion with remote condenser. Hydronic baseboard heating is also provided as required by NECB 2015.

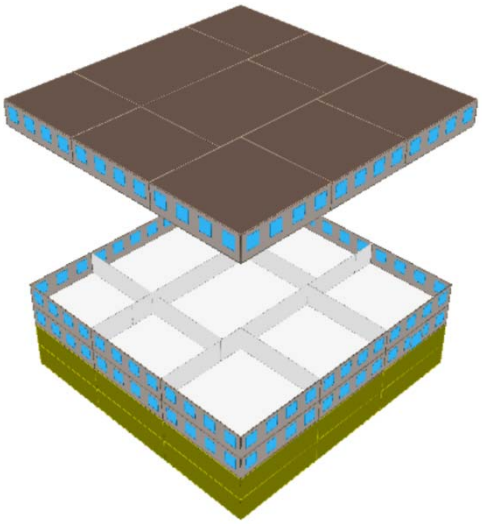

Figure 2 NECB Archetype Large MURB

Big Box Store

Bid Box Store is 1 storey structure having a total floor area of 9290 square metres. Its HVAC system consists of constant volume based single-zone make-up air unit with baseboard heating. Heating is provided by gas fired furnace while cooling system is direct expansion type air cooled.

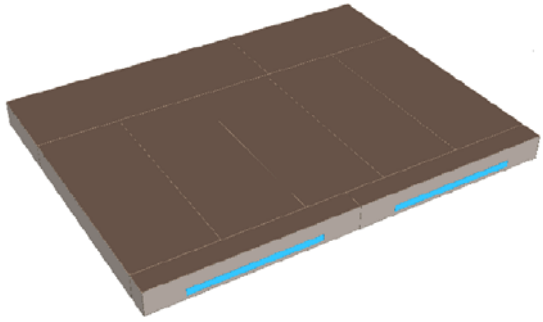

Figure 3 NECB Archetype Big Box Store

SIMULATION FOR NECB ARCHETYPE LARGE OFFICE

NECB 2015 baseline simulation results

Table 3 shows the simulation results for large office obtained for NECB 2015 compliant baseline simulations. It can be noted from the results that the energy consumption and the energy use intensity generally increase with the increasing heating degree days (HDD) as we go from lower HDD (zone 4) to higher HDD (Zone 8).

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Table 3 Large Office Energy consumption as per NECB 2015Baseline

Location (Zone)	HDD	Total Energy (ekWh/Yr)	Total Energy/Area (ekWh/m^2/Yr)
Victoria	2650	1,498,969.89	112.04
Windsor	3400	1,698,867.75	126.98
Montreal	4200	1,790,232.85	133.81
Edmonton	5120	1,781,845.17	133.18
Fort McMurray	6250	1,848,558.60	138.17
Yellow Knife	8170	2,147,348.67	160.50
Average		1,794,303.82	134.11

Energy Efficiency Measures

The proposed energy efficiency measures are grouped into tiers in line with the SC-EEB envisioned tiered energy codes. 'Tier'-wise energy efficiency measures considered are summarized in subsequent paragraphs. Each 'tier' is exploratory and not intended to imply if has been endorsed as a code requirement by SC-EEB or another body.

'Tier 1' Energy Efficiency Measures

'Tier 1' energy efficiency measures are the ones being incorporated in current code cycle as interim changes to the NECB 2015 (published as NECB 2017). These measures were modeled during a previous study (Knapp, 2017) and are presented here as they set the platform for further. Tier 1 energy efficiency measures include:

- Removal of thermal bridging exemption from the NECB 2015 (two separate cases including high and low thermal bridging are simulated). The effect of thermal bridging which reduces the effectiveness of the insulation because of the penetration of the conductive building envelope elements, was previously exempted in NECB.
- Reduced skylight area from 5% to 3%
- Reduced thermal transmittance of opaque assemblies to that of 85% of NECB 2015
- Reduced thermal transmittance of fenestration to that of 85% of NECB 2015
- Changes to space lighting power densities
- Energy recovery system

'Tier 2' Energy Efficiency Measures

'Tier 2' energy efficiency measures are comprised of the proposed additional changes to NECB 2015 which could not be fully developed included in the interim changes being published in 2018[3], and some additional measures. Tier 2 energy efficiency measures are proposed to be incorporated in the 2020 code cycle. They include:

- Variable frequency drives (VFDs) on pumps, compressors, and condensers
- Domestic hot water recirculation point of use water heaters
- Demand control ventilation system
- Condensing boiler for hot water loop
- High efficiency chilled and hot water plant systems
- Automatic receptacle controls
- Occupancy controls
- Daylight controls
- Building automation system (BAS)

To simulate the effect of automatic receptacle controls, and occupancy controls, the equipment hourly profile and lighting schedule are reduced by 10% each of NECB 2015. Similarly, to simulate the effect of building automation system, occupancy and lighting schedules are adjusted by 10% of NECB 2015 (Ashrae, 2010).

'Tier 3' Energy Efficiency Measures

'Tier 3' measures are explored for potential inclusion during a 2025 code cycle. They include:

- Use of radiant heating and cooling technologies
- High-efficiency rooftop units (RTUs)
- Natural ventilation system, which allows ventilation without mechanical systems
- Pre-heating the incoming outside air with solar wall
- Optimizing colour rendering index (CRA) and further reduction in lighting power density

Energy use reduction by radiant heating and cooling is modelled outside Can-Quest. An earlier study conducted by (Kwong et al., 2017) has concluded that radiant slab cooling system reduces the energy consumption by 34% as compared to the conventional variable air volume system while providing the same level of comfort. The same approach is used where the space cooling load is reduced to that of the NECB 2015 baseline simulations. Adjusting the Color Rendering Index (CRI) of the light source to the space function will help use low power lighting. From the energy simulation point of view, this measure will result in reduced lighting power density (LPD). To simulate the effect of the optimized CRI and take into account the future

[3] The code development process relies heavily on volunteer contributions.

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development of lighting technology, the interior spaces LPD is reduced by 10% of NECB 2015.

'Tier 4' Energy Efficiency Measures

'Tier 4' energy efficiency measures include:

- Water loop heat pump
- Displacement ventilation system
- Exterior lighting optimization
- Use of high efficiency condensing water heaters
- Air handling system optimization

These measures were explored for potential inclusion in a 2030 code. The energy efficiency measures are modelled individually to identify the percentage savings in overall energy consumption. The combined savings as per different tiers (except 'Tier 1') are approximated by summing up the savings of individual measures without taking into consideration the interactions between them. This simplification of the combined savings is expected to result in overestimation of certain effects. Since, there is no direct method available within the current version of Can-Quest to model the displacement ventilation system, article from ASHRAE Journal (ASHRAE, September 2004) was consulted. It is reported that displacement ventilation reduces cooling load by 30-75% and increases supply and return fan energy by 35 to 50%. Hence for the present study, the energy savings of displacement ventilation system is approximated by adjusting the NECB 2015 baseline cooling load and the fans energy by the averages of the above-mentioned percentages, i.e. 52.5 and 42.5% respectively.

SIMULATION RESULTS

'Tier 1' (Interim changes to NECB 2015)

Two separate baseline cases for high and low thermal bridging are simulated. Relative to the high thermal bridging, it is found that removing the exemption for thermal bridging and adding bypass control to the energy recovery ventilation (ERV) has the greatest impact.

Removing thermal bridging reduces the energy consumption by 4.2% in zone 4, 9.3% in zone 8, and has an average impact of 6.8% taken across all six climate zones. Adding the requirement for energy recovery system to be 50% effective in recovering the latent heat along with bypass control reduces energy consumption by 8.6% in zone 4, 3.4% in zone 8 and has an average impact of 5.7% taken across all six climate zones.

The additional changes have been reported to lead to a total average reduction of 20.1% across all climate zones for the large office. Relative to the low thermal bridging baseline, removing the exemption for thermal bridging reduces energy consumption by an average of 2.3% with a total average reduction from all proposed interim changes of 16.3%. A breakdown of the annual energy savings from the interim changes to NECB 2015 is shown in figure 4.

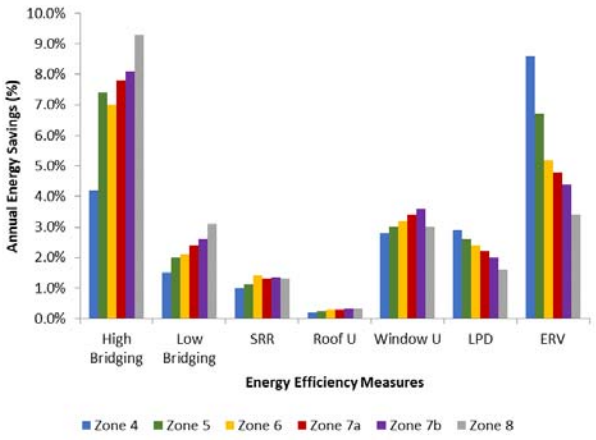

Figure 4 Annual Energy Savings for Tier 1 measures

'Tier 2' (Code cycle 2020)

Additional changes to NECB 2015

The annual energy savings resulting from the additional changes to NECB 2015 are shown in figure 5 and figure 6. Installing the variable frequency drives has the greatest impact. This measure reduces the overall energy consumption of large office archetype by 9% in zone 4, 4.1% in zone 8 and has the impact of 7.2% when averaged out across all climate zones.

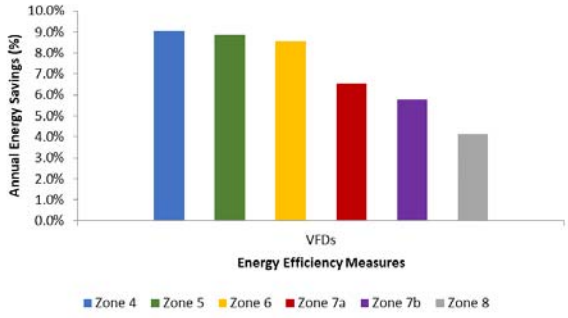

Figure 5 Energy Savings from Variable Frequency Drives

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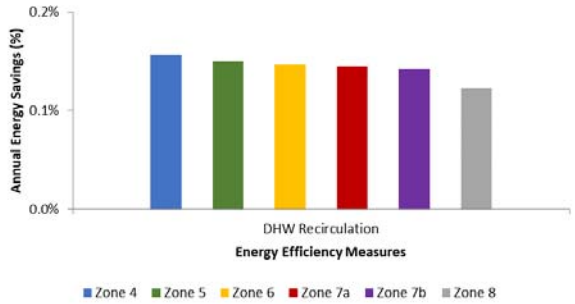

Figure 6 Energy Savings from Domestic Hot Water Recirculation

The domestic hot water recirculation point of use water heater results in an average annual energy savings of 0.1%. With all the measures of additional interim changes to NECB 2015 combined, the annual average energy savings are 7.3%.

Additional 'Tier 2' Measures

Of all the measures modelled in this category, the daylight controls save the most energy with a climate zone averaged impact of 4.9% on the overall energy consumption of the large office (6.4% for Zone 4, and 2.2% for Zone 8).

Use of condensing boiler water loop system is the second most influential measure after daylight control, reducing the energy consumption by an average of 3.9% to be followed by the occupancy control and building automation system (BAS) with an average annual energy reduction of 1.8, and 1.7% respectively. No savings in annual energy consumption by condensing boiler is taken into account for climate zone 8.

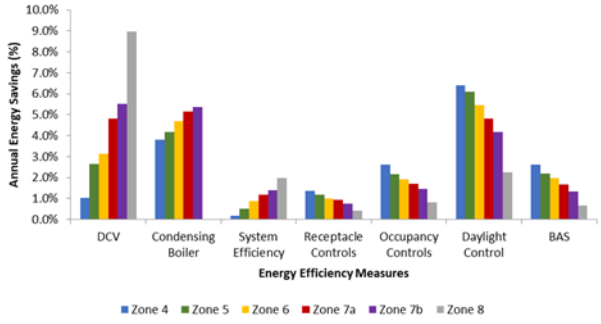

Figure 7 Annual Energy Savings from Additional Tier 2 measures

'Tier 3' (Code cycle 2025)

Energy savings from the Code Cycle 2025 measures are reported in Figure 8.

Natural ventilation measure saves most of the energy in this category with a climate zone average of 7.3%. High-efficiency RTU's and the CRI optimization are having average energy use reduction of 2.9 and 2% respectively.

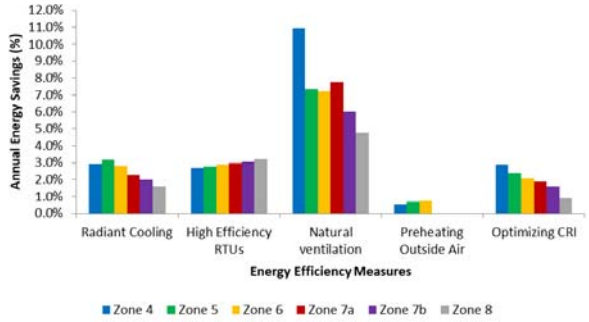

Figure 8 Annual Energy Savings from Tier 3 measures

The climate zone-wise savings with the RTU measures range from 2.7 for Zone 4 to 3.2% for Zone 8. The energy savings pattern of the CRI optimisation is similar to any other lighting retrofit, being higher for low HDD climate zone and lower for higher HDD climate zones. The pre-heating of supply air by the solar wall is only considered for climate zone 4, 5, and 6 only with an average impact of 0.3%.

Tier 4 (Code Cycle 2030)

Water loop heat pump HVAC system has the highest impact on energy consumption with an average of 16.1% whereas the displacement ventilation reduces the average annual energy consumption by 4.5%. The exterior lighting measure has an average impact of 3.8%.

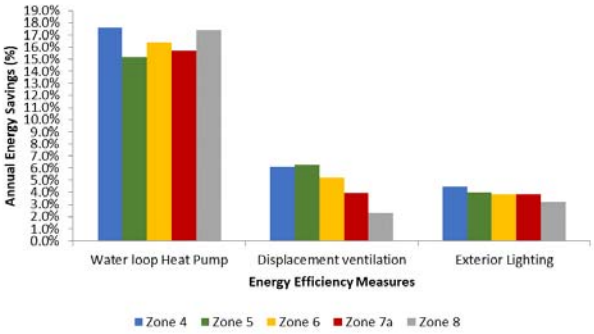

Figure 9 Annual Energy Savings from Tier 4 measures

The measures related to condensing water heater and air handling sizing optimisation has an average impact of 0.1, and 0.2 respectively.

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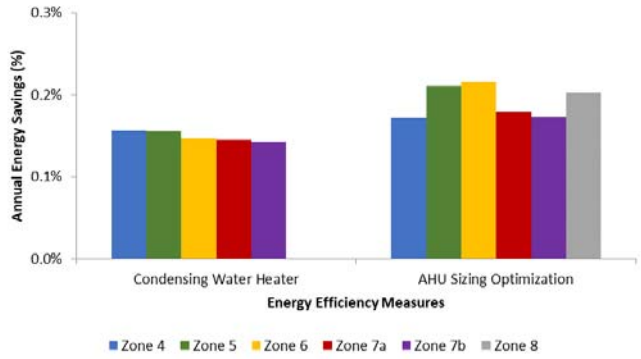

Figure 10 Annual Energy Savings from Tier 4 measures

MODELLING LIMITATIONS

In the present study, not all of the SC-EEB proposed energy efficiency measures could be simulated. Those measures include cooling systems using Variable Refrigerant Flow (VRF) technologies, active chilled beams, air curtains, combined heat and power generation, dedicated outdoor air system, solar absorption cooling, drain water heat recovery and motorized and solar blinds. This choice was required because of modelling limitation in Can-Quest where system specific data libraries are needed. Hence, further studies are recommended for these measures which will potentially include diversifying the modelling and simulation tools beyond Can-Quest.

CONCLUSIONS

Energy efficiency measures are simulated for the NECB archetype large office. Comparison of the simulation results with the SC-EEB direction is presented in Figure 11.

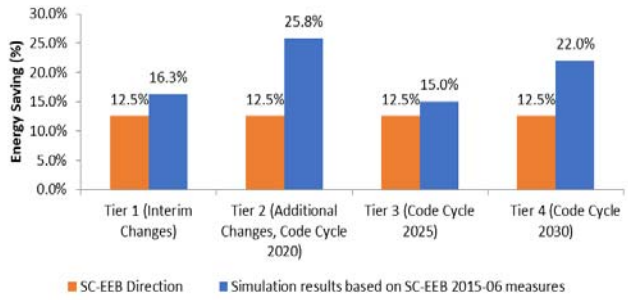

Figure 11 Energy Savings Vs SC-EEB Direction

It is to be noted here that except in tier 1, compatibility issues and interactions within the efficiency measures which may affect the overall saving figures in a combined simulation model are not considered in the present study. The percentage energy savings in tiers is shown per the NECB 2015 baseline.

As next step, in order to get a more representative sense of the energy savings for each tier, the baseline needs to be moved in successive tiers. This exhibits the need to first consolidate on the measures for the tier 1 regarding the implementation concerns and then move on to the next tier. Further, future developments in energy efficient technologies will result in more energy savings for the future code cycles. One such example is the LED lights, which are expected to reduce the lighting power density by 60% from the current level by the year 2035 (Newsham, 2017). Lower LPD combined with advanced control options are expected to result in even higher energy savings.

Simulation of energy efficiency measures for other NECB archetypes including Large Multi-Unit Residential Building (MURB), Big Box Store, Secondary School, and Strip Mall will be undertaken in a future stud

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