BENCHMARKING AND SCREENING NEW BUILDING ENERGY MODELS IN THE TORONTO CONTEXT

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Benchmarking and Screening New Building Energy Models in the Toronto Context

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Abstract

Building energy modeling is a well-established field but there is a lack of research to support design guidance and energy benchmarking using simulated results. This study presents a methodology for collecting information about planned buildings in Toronto from uploaded building energy modelling files, to be used as a basis of comparison for future models. The methodology includes the development of an algorithm for automating the generation of baseline building models. Key building design and performance characteristics are identified for inclusion in a database of new buildings in Toronto, and a feedback mechanism, to provide design guidance through comparative analysis and program screening, is detailed. The resultant database can be used by individual building design teams, urban planners, or policy-makers, as they work together to reduce the greenhouse gas emissions in Toronto through increased energy efficiency in the built environment.

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Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

Climate change is arguably the most critical issue of our time, and demands a response from all countries and industries. As the *Intergovernmental Panel on Climate Change 2014* report states, "continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive, and irreversible impacts for people and ecosystems" (IPCC 2014). Substantial reductions in greenhouse gas (GHG) emissions worldwide are needed to limit climate change and mitigate its effects on current and future ecosystems (IPCC 2014).

Within Canada, the buildings economic sector generated 86 Mt CO_2 equivalent in 2013, which accounted for 12% of the nation's total GHG emissions that year (MECC 2016), exclusive of indirect emissions from the generation of electricity used in these buildings. The *Energy Fact Book: 2015-2016* (NRCan 2015) accounts 29% of Canada's secondary energy use in 2012 to energy consumption in the residential, commercial, and institutional sectors. These statistics demonstrate an opportunity for reduction of greenhouse gas emissions through reduction in energy consumption in the building sector.

As the largest Canadian city, Toronto's buildings contribute significantly to energy consumption and greenhouse gas emissions in Canada. Toronto has experienced rapid growth of population and development of new buildings: between 2011 and 2015, over 2 million square metres of residential space and 950,000 square metres of non-residential space has been built in the downtown core, with additional development projects in the approval and construction stages (TOcore 2016). In January 2016, the Toronto planning department TOcore initiative completed its *Energy Working Group Report* (TOcore Energy Working Group 2016) which discusses the existing conditions and emerging priorities for the downtown core of Toronto. The report focuses on developing a strategy for addressing the growth in electricity demand as Toronto's building stock expands, in particular looking to meet the city's greenhouse gas reduction targets and improve the resilience in the context of climate change (TOcore Energy Working Group 2016). While existing buildings form the majority of buildings in Toronto, the rapid new development "presents [an opportunity] to address these issues early on through improved design and alternative infrastructure" (TOcore Energy Working Group 2016).

Similarly, the Toronto2030 District is a private sector, interdisciplinary initiative looking to reduce carbon emissions in the downtown core of Toronto by finding efficiencies at a community scale (Architecture 2030 2014). In addition to finding economies of scale as energy efficient products and technologies are implemented in larger quantities, the district approach also enables intelligent control of the energy consumption within the whole community as a smart-grid (2030 Districts 2016). Further, it supports the establishment of a critical mass of community engagement and interest in energy conservation activities, which contribute greatly to reductions in carbon emissions (REMI Network 2015).

Predicting the impact of new buildings on the energy demands of a community or district is challenging since no measured energy consumption data is available. Estimated annual energy consumption from computer simulations can be used as a substitute to facilitate more realistic predictions of district energy consumption patterns, however no database currently exists for the simulated energy performance of new and planned buildings in Toronto (Babaei, et al. 2015). Such a database would be a useful resource for urban planning teams and utility companies who are all working to reduce the energy consumption – and thus carbon emissions – of buildings (TOcore Energy Working Group 2016). Moreover, performing comparative benchmarking using this database can identify opportunities for improvement at the individual building scale (Chung 2011), assisting Toronto in achieving its carbon emissions reduction targets despite the city's rapid rate of development.

1.1 Research Objective

The objective of this research is to develop the underlying methodology for screening and benchmarking new buildings based on uploaded building energy models (BEMs). This methodology can be used to gather a database of simulated building energy performance along with characteristics for new buildings in Toronto.

1.2 Research Questions

Three research questions must be investigated to achieve this research objective:

1. What information must be extracted from BEM output files to screen a proposed building against key energy conservation programs relevant to the Toronto context?
2. How can a comparative baseline building be generated based on an uploaded BEM (eQUEST) input file?

3. What specific design input can be provided to the designer as a result of this screening and benchmarking process?

1.3 Research Output

The Toronto2030 district planners have identified their desire for a tool that would (a) support designers of new buildings as they work to steadily improve the energy efficiency of their buildings, and (b) develop a database of the simulated performance and characteristics of proposed buildings in Toronto. A screening process will be used to incentivize designers to participate in the collection of this dataset: the performance of the proposed building will be evaluated against each of four building programs relevant to the Toronto new construction context – Leadership in Energy Efficiency Design v4 Building Design and Construction (LEED v4 BD+C); the 2030 Challenge; the Toronto Green Standard (TGS), Tiers 1 and 2; and the SaveOnEnergy *High Performance New Construction* Incentive (HPNC) custom path.

The desired output of this research is the development of algorithms to support the following tool functionality:

1. Take the building energy model of a proposed new building;
2. Generate baseline model of comparison;
3. Screen the building against four Toronto-based programs;
4. Populate a database of the estimated energy consumption of new Toronto buildings; and
5. Provide design support through comparative benchmarking and analysis.

Software development for the above-described tool is not within the scope of this research, however these algorithms should be written in a way that facilitates the future tool creation by others. The eventual tool would be intended for use during the design development phase of the project as well as after completion of the design. For a building in the design development stage, the tool will indicate the building's potential performance in each program and display the building characteristics and energy performance in comparison with other buildings in the database. Through this comparative analysis, the designer can look for opportunities to improve the performance of their building, benchmark their design against similar buildings, or discover potential deficiencies in their energy model inputs.

For a completed building design, the tool will evaluate the building's performance in each program, generate the appropriate application documents, and provide all of the generated eQUEST simulation files. The building characteristics and estimated performance will be added to the database, and can be used by Toronto city planning teams and utilities. The designer can also access the comparative analysis results to see how their building performs in relation to other buildings in the database. This function can be useful for design communication purposes by allowing the design team to recognize, and demonstrate to their clients, the impact of different design decisions.

2.0 Context

The following sub-sections discuss the current state of research and practice in building energy benchmarking using simulated energy performance, and identify the knowledge gap that this research paper aims to address. This discussion includes further uses of data collection for urban energy planning and design support. The energy conservation programs and energy modelling software used in this project are also defined.

2.1 Energy Benchmarking

Building energy benchmarking, defined simply by Pérez-Lombard *et al.* as "the comparison of energy use in buildings of similar characteristics" (Perez-Lombard, et al. 2009), provides an opportunity for energy efficiency measures to be identified and assessed. Benchmarking can be used to inform design through performance indicators – which draw attention to areas of poor performance – and public disclosure of results, which can promote competition among building owners and designers (Chung 2011).

The data used to perform energy benchmarking can be generated using three strategies: measurement, survey, and simulation (Babaei, et al. 2015). The measurement and survey strategies collect data based on the actual performance of buildings, either quantitatively through directly measurement of energy consumption, or qualitatively through interviews with building occupants and operators (Babaei, et al. 2015). New and proposed buildings are not able to use these data collection strategies, since actual performance data is not available; instead computer software is used to simulate the building performance under defined climatic conditions (Zhao and Magoules 2012). The results of this simulation can be used to perform a type of energy benchmarking of a building, for instance by comparing the building's estimated energy performance to a collection of the measured performance of other similar existing buildings (Perez-Lombard, et al. 2009). Numerous "whole-building energy simulation programs" have been developed for this purpose, and their individual merit and use is discussed in detail by Crawley, *et al*. (Crawley, et al. 2008).

Some research has been done into the use of simulation as a strategy for developing a benchmarking system (Chung 2011), with notable studies on collected simulation data from buildings in Hong Kong (Lee and Burnett 2008) and California (Kinney and Piette 2002). The generation of a database from computer simulations for use in predicting the energy performance of new buildings has also been studied, as summarized by Foucquier, *et al*. (Foucquier, et al. 2013).

A study of available building energy data sets by Babaei, *et al*. (Babaei, et al. 2015), however, did not identify any collections of simulated energy performance in the Canadian context.

In part due to the lack of collected data, energy benchmarking for a proposed new building is most often accomplished by comparing the energy performance of the proposed building to the energy performance of the same building designed to meet a regulated set of minimum building and equipment performance characteristics (Perez-Lombard, et al. 2009). This self-referential comparison is achieved by creating two computer energy simulations with matching geometry and activity profiles, but differing building envelope, mechanical, and electrical systems (Rosenberg and Eley 2013). The characteristics of the reference building, known as a baseline building of comparison, can be prescribed by local building code or national standard (Ministry of Municipal Affairs and Housing 2012). Many municipalities, including Toronto, regulate a minimum level of performance above this baseline benchmarking strategy: proposed new buildings are required to meet and/or exceed the energy performance of the baseline building (Perez-Lombard, et al. 2009).

If an appropriate set of data is available, benchmarking can be accomplished by comparing the energy performance of a proposed building with its comparable peers (Kinney and Piette 2002). Two existing tools that enable comparative building energy benchmarking analysis are the United States Environmental Protection Agency's (EPA) *Target Finder* calculator, and the American Institute of Architects' *2030 Design Data Exchange* (DDx). *Target Finder* compares estimated building energy consumption with surveyed national energy use intensity values (US EPA n.d.), while *DDx* benchmarks against a data set collected from other users of the program (The American Institute of Architects 2016).

There is room for improvement in the application of these tools to new or proposed buildings. *Target Finder* compares the simulated energy performance of a building against actual building data, collected using the national census as a survey (US EPA n.d.). This provides valuable insight into the current state-of-affairs in the built environment, and can show how a new building will fit into the existing energy context. Energy simulations, however, are known to provide performance results that differ from the actual energy consumption of a building, due to the many assumptions that must be made about the occupancy and use of the building (Babaei, et al. 2015). Considering this limitation, there is a concern that *Target Finder*, by benchmarking simulated results against surveyed energy performance, is establishing a false or unrealistic comparison. Further, the proposed building is compared to the median value of the database, despite recent improvements to the energy performance requirements and available technologies that cause newer buildings to have lower annual energy consumption values. There is no option to filter or normalize the data to tailor the comparison.

While *DDx* compares all buildings using the same data collection strategy, it bases its comparison on voluntary data submission (The American Institute of Architects 2016). This has the potential of creating a biased database as those designers with well-performing buildings have greater incentive to upload their data (Haapio and Viitaniemi 2008). In addition, the tool relies on manual input of energy consumption data and does not require that this data be generated using a computer simulation, although it is recommended (The American Institute of Architects 2016). A tool that gathers data directly from the energy model files could ensure an equal basis of comparison while a helpful output would help encourage all building designers to participate in the data collection, not just the top performers.

The design of energy efficient and sustainable buildings is critical to the success of Toronto's greenhouse gas emission reduction targets, yet high-performance building design is still an emerging industry. Existing tools show the performance of new building designs in comparison with their peers, but are not intended to be used as a design assistance tool, rather as simply a means to benchmark. Both *DDx* and *Target Finder* focus on energy use intensity as the primary analysis metric and do not present data about building design characteristics for comparison or analysis. An analysis tool based on comparative benchmarking can help facilitate improved design (Perez-Lombard, et al. 2009, Chung 2011, Allegrini, et al. 2015).

There are several tools available for the simulation of a building's energy consumption, each designed to focus on different aspects of the built environment (Haapio and Viitaniemi 2008). Despite this, few energy simulation tools have been developed for use by architects during the design phase; most require the user to have engineering expertise to comfortably understand and interpret the results (Attia, et al. 2012). ZEBO, an energy simulation tool developed by Attia, *et al*. (Attia, et al. 2012) is a notable exception. This design tool targets architects as its audience and presents building simulation optimization results in a visually comprehensible format. Self-referential energy benchmarking is used to assess the value of different design options.

A 2015 study performed by Integral Group (Integral Group 2015) looked at the stakeholder reaction to a proposed energy benchmarking and reporting requirement for buildings in Toronto. When asked about public disclosure of energy and water use by buildings, workshop participants noted that this would provide welcome perspective on the relative performance of different buildings (Integral Group 2015). This aligns with the academic research illustrating that comparative benchmarking can be used to bring public pressure on buildings demonstrating poor energy performance and that analysis can suggest possible reasons for poor performance (Chung 2011). A set of building characteristics and metrics is thus desired to help direct building design towards meaningful energy conservation while allowing for creativity and variation in the design and implementation of these metrics, and becomes a catalogue of possible solutions rather than a recipe for sustainability (Kesik 2015).

2.2 Comparative Analysis and KPI as Design Guidance Tools

Key performance indicators (KPI) are quantifiable metrics used to assess building performance, most often in terms of its environmental, economic and social characteristics (ALwaer and Clements-Croome 2010). KPI have been widely discussed in literature, and defined for building assessment (Hussain, et al. 2013) (Mwasha, Williams and Iwaro 2011). KPI are often used as targets or goals for a building, but can be complex and difficult to decipher (Feifer 2011). KPI are used to define success at achieving project goals, but may not be granular enough for use in design decision-making.

In contrast, the comparative analysis process that will be discussed in this study is defined as the benchmarking of the characteristics of a proposed building against the same characteristics in a set of the building's 'peers,' looking both in absolute terms, and in correlation with building energy consumption. In the context of this report, comparative analysis is intended to provide design guidance by analysing the characteristics of a building in relation to similar buildings to identify potential areas of improvement in the design (Perez-Lombard, et al. 2009).

This analysis can assist in the design of high performance buildings by guiding designers in their decision-making. As the technology and design of high performance buildings advances, this comparative analysis can help designers stay informed of the current industry best practices (Attia, et al. 2012). Further, building designers, owners, and decision-makers can use this comparison to identify where their proposed building ranks in the current market, functioning as a "public yardstick" (Chung 2011) that can provide pressure to improve the performance of their building (Perez-Lombard, et al. 2009). Establishing a visual correlation provided through graphical comparative analysis allows the results to be comprehensible to all building stakeholders (Kesik 2015).

2.3 Urban Energy Planning

Beyond design guidance at the individual building scale, there is growing interest in a community-level dataset to assist in urban planning who are striving to understand and coordinate the energy demand, generation potential, and storage capacity within a district (Reinhart and Davila 2016, Boston Redevelopment Authority Planning Division 2015, Han, et al. 2013). In Toronto, this interest manifests in initiatives like the TOcore Energy Working Group and the Toronto2030 eco-district.

A review of urban energy modelling tools by Allegrini, *et al*. (Allegrini, et al. 2015) notes the specific challenge of providing decision-makers with support during early stages of building and urban design. Yet, software has been developed to model the energy consumption of existing buildings at a neighbourhood level and is being expanded to look at the predicted energy consumption of new buildings (Reinhart and Davila 2016, Davila, Reinhard and Bernis 2016, Ascione, et al. 2013). This energy performance data can be combined with Geographic Information System (GIS) data to create urban energy maps, which can be used to inform urban planning, drive consumer engagement, and identify progress toward community-scale energy conservation targets.

These new software developments represent a powerful tool for working toward the Toronto2030 District goals of understanding where energy use occurs across the district and cutting district-wide carbon emissions in half by the year 2030 (Architecture 2030 2014). A database of new building simulated consumption can contribute to the urban data, showing how a new building will fit into the existing district and what types of loads can be expected (Tardioli, et al. 2015, Kavgic, et al. 2010). Community planners would then be able to develop incentive programs based on realistic predictions of upcoming new building developments and tailor land-use zoning appropriately (Han, et al. 2013, Fracastoro and Serraino 2011).

2.4 Programs

Four programs have been selected as focus for the screening function of this project based on their relevance in the Toronto building industry context: Leadership in Energy Efficiency

Design (LEED) v4 Building Design and Construction (BD+C), the 2030 Challenge, Toronto Green Standard, and the Save On Energy High Performance New Construction Incentive.

These four programs all assess the energy performance of the proposed building, but each uses a different metric and has a different minimum requirement. Further, each program has different requirements regarding the submission timeline – the stage of project completion at which the energy performance is assessed. These differing program characteristics are juxtaposed in Table 1, and each program is discussed in detail in Sections 2.4.1 through 2.4.4.

2.4.1 LEED v4 BD+C

LEED is a green building rating system, designed to encourage sustainable design in the built environment. Tiered certification levels are awarded to buildings that meet all the LEED prerequisites based on the number of points that are achieved under LEED credits in eight categories; top performing buildings are awarded LEED Platinum certification, followed by LEED Gold, Silver, and Certified ratings. LEED v4 was first introduced in 2013, and beginning in October 2016 all LEED projects must follow the v4 system (Long 2014).

There are a number of variations on the LEED rating system, which enable many different building projects and building types to target LEED certification. This project looks exclusively at the LEED BD+C rating system for new construction projects. In this system, the energy performance of a new building is assessed using predicted annual energy cost savings compared to a baseline building of comparison. As a prerequisite to LEED certification, the new building must demonstrate a minimum of 5% annual energy cost savings over a baseline building based on ASHRAE Standard 90.1-2010 (U.S. Green Building Council 2013). Further energy cost savings count toward points in the Atmosphere and Energy category, under the Optimize Energy Performance credit.

As of 2016, over 550 buildings in Toronto have been certified under the LEED rating system (CaGBC n.d.). This represents a significant portion of the LEED buildings in Canada, and demonstrates the popularity of the program in Toronto. LEED (and other sustainably-certified) buildings benefit from increased market value and demand due to tenant preferences, market drivers, and reputational benefit as healthier or more environmentally conscious (Kok, McGraw and Quigley 2011, Eichholtz, Kok and Yonder 2012).

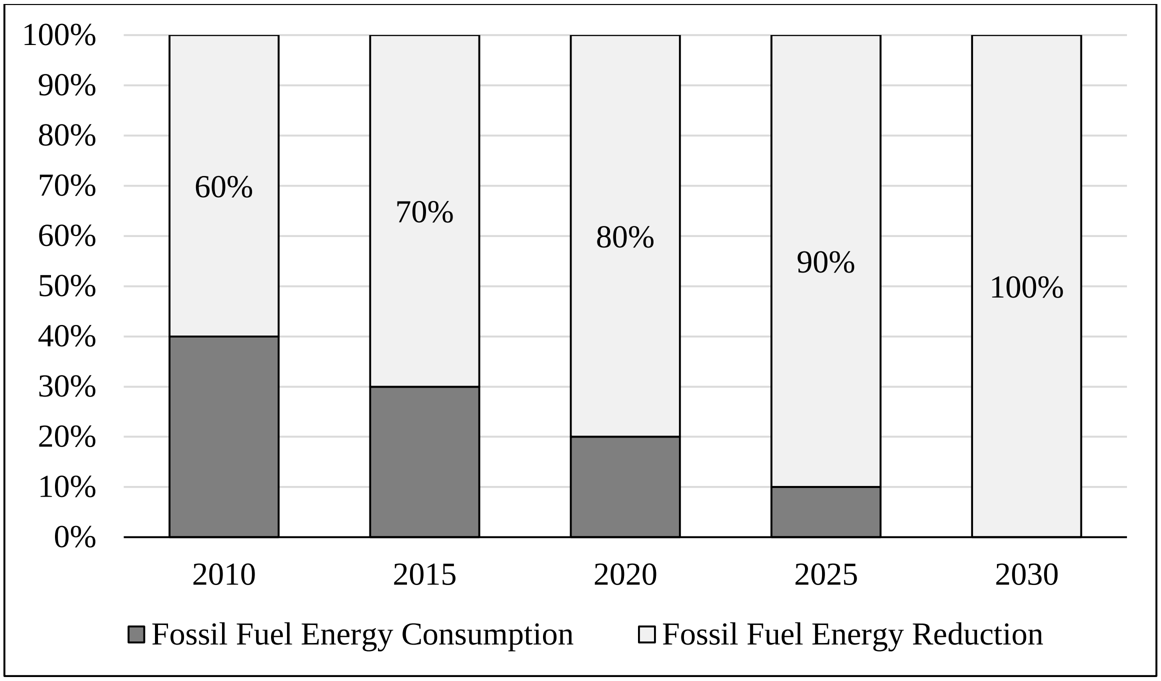
Table 1 – Program Comparison

	LEED v4 BD+C	2030 Challenge	TGS	HPNC
Energy Performance Metric	Annual energy cost savings	Annual site energy use intensity	Annual energy savings	Annual energy savings or peak demand savings over baseline building
Minimum Requirement	5% savings above baseline building	70% reduction from regional average annual site EUI (2016 target)	15% improvement in annual energy consumption over baseline building	Minimum incentive value of $5,000
Submission Timeline	Submission at end of construction	No submission, target based on year of project completion of design	Submission with development application, Tier 2 verified at construction stage	Estimate at project start, full submission at project completion/ occupancy
Building Type	New buildings	New buildings	Any new development	New buildings
Program Administrator	CaGBC	Architecture 2030	City of Toronto	Toronto Hydro
Financial Incentives	None	None	Reduced development fees	Cash incentive for performance improvement
Baseline Reference Standard	ASHRAE 90.1-2010	Published target EUI	OBC 2012	OBC 2012
Energy Modelling Required for Baseline	Yes	No	Yes	Yes

2.4.2 2030 Challenge

The 2030 Challenge is a voluntary design initiative that targets aggressive reductions in carbon emissions from buildings over the next few decades to respond to the contribution of buildings to climate change. This initiative posits that all new buildings and major renovations should be carbon neutral by the year 2030, based on a staged reduction of allowable carbon emissions for all buildings from 2010 through 2030 as shown in Figure 1 (Architecture 2030 2014).

Figure 1 – 2030 Challenge Targets by Year (Architecture 2030 2014)



The 2030 Challenge measures a building's success by comparing its predicted annual site energy use intensity (EUI) to published target goals, characterized by building type and region. For Ontario, these targets are based on the Natural Resources Canada *Comprehensive Energy Use Database* (Architecture 2030 n.d).

The Toronto2030 District, described in Section 1.0, is an expansion upon the mandate of the 2030 Challenge. Both initiatives have been formally adopted by the Ontario Association of Architects, and design firms in Ontario and Toronto are encouraged to work towards meeting the 2030 Challenge targets (2030 Districts 2016). For this reason, the 2030 Challenge has been included in the program screening of this report.

2.4.3 Toronto Green Standard

The Toronto Green Standard (TGS) is a set of performance measures designed to improve the sustainability of Toronto's built environment. The purpose of the TGS is to support Toronto's *Climate Change Action Plan*, which targets an 80% reduction in city-wide greenhouse gas emissions by 2050 (Livegreen Toronto 2015). There are two tiers to the standard: Tier 1 outlines the mandatory requirements for all new building developments in Toronto, while Tier 2 is a voluntary set of measures with higher performance standards than Tier 1. Financial incentives are available for projects that achieve the Tier 2 requirements.

The energy performance requirements of the TGS are more stringent than the Ontario Building Code (OBC). Proposed buildings must demonstrate annual energy efficiency percentage improvements over a baseline building of comparison that is compliant with OBC 2012 requirements – minimum 15% improvement for Tier 1, and at least 25% for Tier 2 (Livegreen Toronto 2015). The annual energy savings must be shown in terms of annual energy consumption, and seasonal peak demand savings. Renewable energy generation cannot contribute to the savings.

The TGS is included as one of the four screening programs in this report due to the requirement that all new buildings in Toronto must meet TGS Tier 1 standard. Demonstrating energy performance at the Tier 2 level may encourage building design teams to strive to achieve the higher level, and financial benefit may be found for the development. Note that buildings falling under Part 9 of the OBC are excluded from the scope of this project.

It is worth noting that the City of Toronto has undertaken a review of the TGS requirements in preparation for the release of OBC 2017, which will have more stringent energy efficiency requirements. The review recommended that a future version of the TGS use a target-based approach to measure energy performance, specifically suggesting that thermal energy demand energy use intensity would be a good target metric for the program (Integral Group 2015). Implementation of this recommendation will be cause for adjustment of the output of this research.

2.4.4 High Performance New Construction Incentive (HPNC)

The Save On Energy *High Performance New Construction* (HPNC) incentive encourages building designers and owners to explore energy efficiency opportunities in their new buildings (Save On Energy 2016). The incentive is one of several Save On Energy conservation programs in Ontario, designed by the Independent Electricity System Operator (IESO), and facilitated by the local electricity utility. HPNC is designed to help offset the incremental cost of energy efficient equipment and design strategies, as well as encouraging participants to consider energy efficiency measures in their design. Funding may be provided to the building owner, design decision-maker, and energy modeller, based on eligibility criteria and funding limits.

Two tracks are available: Engineered Track and Custom Track; this report focuses exclusively on the Custom Track. Custom Track incentive amounts are calculated based on the incremental energy performance improvement of a proposed building, over an OBC 2012 baseline building. Funding is provided per unit of annual energy savings or cooling-season peak demand savings, and buildings with greater performance improvement are given higher incentive rates. The incentive tiers are show in Table 2; the awarded amount is the greater of either the demand savings incentive value or the energy savings incentive value to a maximum of 50% of the eligible project costs.

Table 2 – HPNC Incentive Tiers (Save On Energy 2016)

% Improvement above Baseline	Demand Savings Incentive	Energy Savings Incentive
0% - 25%	$50/kW	$0.00625/kWh
25.5% - 50%	$100/kW	$0.0125/kWh
50.5% +	$150/kW	$0.01875/kWh

The HPNC incentive has been chosen for screening in this report due to its relevance in the Toronto new construction context. Improving the accessibility of the HPNC incentive may increase its uptake, and support the reduction of Toronto's greenhouse gas emissions, by encouraging building owners to seek greater incentive values.

2.5 Energy Modelling

The energy simulation software used in this research is eQUEST 3.65, a building energy use analysis tool using the DOE-2 simulation engine (Lawrence Berkeley National Laboratory 2016). This software is acknowledged by each of the four energy conservation programs as an acceptable tool for estimated the energy consumption of new buildings.

There are three file-types used by eQUEST that are relevant to this research:

1. .inp – This file-type contains the inputs that define the simulated building using a series of commands, keywords, and numerical values. The file is text-based and uses the Building Description Language of DOE-2. The .inp file-type will be used by the algorithms developed in this research.

2. .bdl – This file-type is generated when an .inp file is loaded in eQUEST. While it appears very similar to the corresponding .inp file, changes made to the .bdl file are not reflected in the eQUEST model, and will be over-written if the .inp file is reloaded. This file-type is useful for this research because of the detailed references it gives to eQUEST library values, but it will not be directly manipulated by the developed algorithms.
3. .sim – This file-type contains the detailed results of the eQUEST simulation, including all hourly, design, and annual reports. The data within the .sim file is used in this research to perform the program screening, and is extracted for collection in the database.

When the eQUEST simulation is performed, the energy performance of the described building is calculated for each hour of one full year, using climatic conditions defined in a weather file (Lawrence Berkeley National Laboratory 2016). Since the output of this research is intended for use in Toronto, all proposed buildings are assumed to be simulated using the same weather file. In the future, a custom weather file can be created to align with the climatic conditions of downtown Toronto, however that element of work is outside of the scope of this project. As a part of the simulation process, the sizing of building services equipment is automatically determined using the calculated peak building demand on the user-defined heating and cooling design days (Lawrence Berkeley National Laboratory 2016).

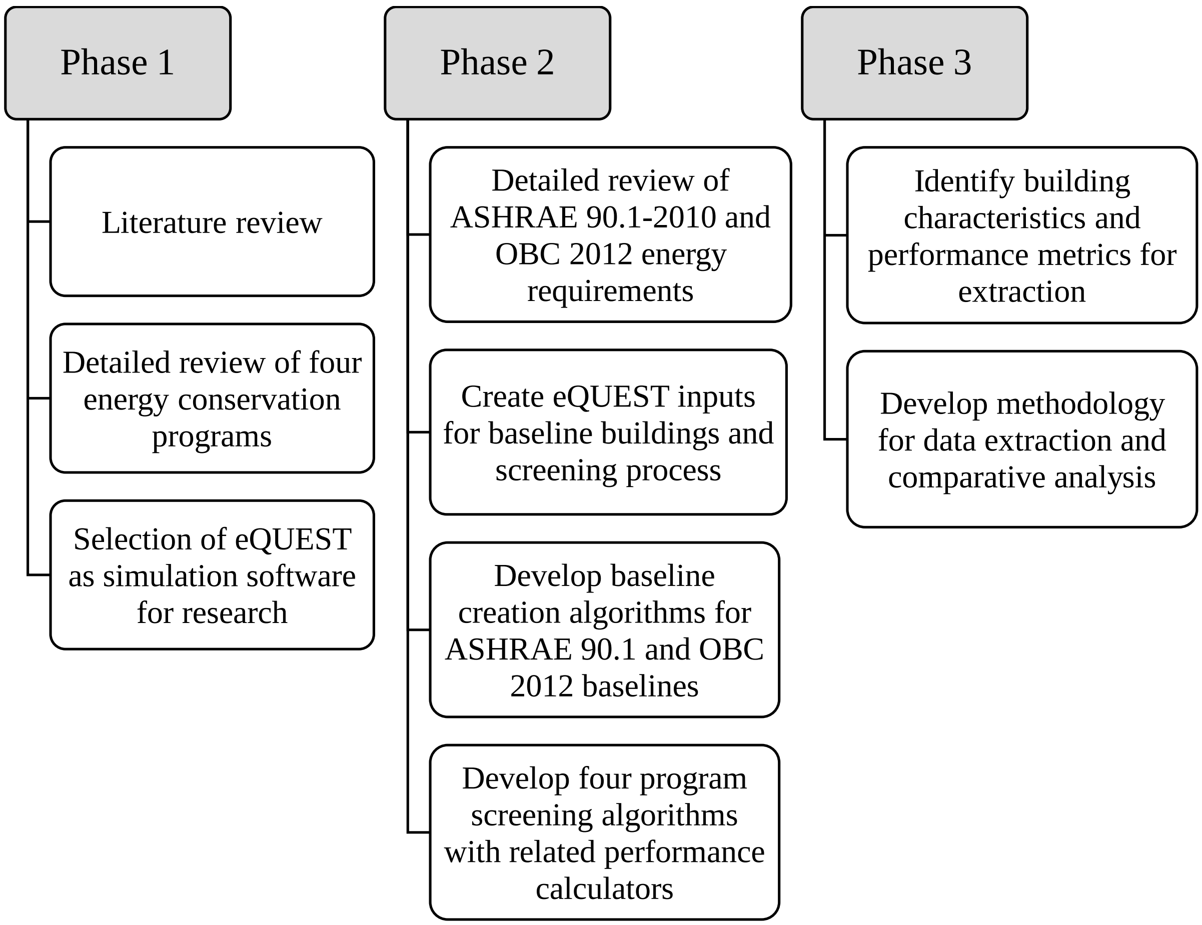
The validity of simulated building energy performance when compared to actual measured performance is a topic of ongoing discussion, particularly because the simulation calibration accuracy is dependent on user expertise, thorough knowledge of a building's detailed design inputs, and appropriate and local climate data (Chung 2011, Babaei, et al. 2015, Fumo 2014, Gould and Hawkins 2015). Nevertheless, Reinhart & Davila (Reinhart and Davila 2016) posit that reviewing simulated building energy use in aggregate causes individual model inaccuracies to average out, and their review of literature demonstrates error ranges between 1% and 19% for total energy use intensity among groups of simulated buildings.

This report acknowledges the limitations of simulated energy performance data, but model validation, calibration, and the performance gap between predicted and actual energy annual consumption rates are beyond the scope of this research and will not be discussed.

3.0 Research Methodology

This project was carried out in three key phases: (1) literature review and screening program research, (2) algorithm development, and (3) building performance analysis and data extraction.

Figure 2 – Project Phases



3.1 Literature Review and Screening Program Research

The literature requiring review extended beyond academic publications and involved a detailed evaluation of the four selected screening programs and their reference standards. The research considered existing comparative analysis tools, benchmarking strategies, and data sets of simulated building performance in the Canadian context, while seeking an academic interest in and demand for these resources.

Next, a detailed review of the four screening programs was performed. This review classified program performance assessment methods, submission documentation requirements, and program-specific calculation methods. Finally, overlapping performance requirements were identified for later use in streamlining the program-screening algorithm.

At this point, eQUEST version 3.65 was selected as the energy simulation software, as it is accepted by all of the programs, and is commonly used in the industry. This software, driven by the DOE-2 simulation engine, uses the engineering method of simulation to estimate energy performance by calculating heat transfer and thermodynamic relationships of the building components under set external climatic conditions (Zhao and Magoules 2012).

Further, it was determined that two baseline buildings of comparison will be needed to perform the screenings for the four selected programs: one to meet the requirements of ASHRAE Standard 90.1-2010, and one to meet the requirements of the Ontario Building Code 2012. A detailed examination of these two reference standards was then performed. This examination determined the characteristics of each standard's baseline building, identifying both the minimum performance requirements and the design characteristics of the baseline building components.

3.2 Baseline-Creation and Program-Screening Algorithm Development

Using the identified baseline requirements, algorithms were developed to automatically generate two eQUEST input files, one for each reference standard. These algorithms outline the overarching decision-making process that must be followed and includes a set of eQUEST inputs, as well as a number of calculation processes to tailor the inputs to match the proposed building. They are written in illustrative pseudo-code, and can be used to inform the future development of an online screening and benchmarking tool. The inputs and algorithms were developed through scrutiny of the eQUEST software, user manual, and example input files, and can be found in Appendices A, B and C of this report.

To screen a proposed building under each program, the detailed information required was then collected: any eQUEST inputs needed to complete the screening were identified and created; the necessary data outputs were identified in the eQUEST output file; any further processing and/or calculations were defined; and a calculator was created in Microsoft Excel to provide the necessary information output for each program's submission documentation. Using these developed resources, and continuing from the automated generation of a baseline input file for each reference standard, an algorithm for screening the proposed building under all four programs was created.

The above algorithms were distilled into an outline flow chart for a future online tool. The software for this tool will be developed by others to match the algorithms and methodology that have been detailed in this investigation.

3.3 Building Performance Analysis and Data Extraction

A key output of this research was a methodology for gathering key building characteristics into a database of new building energy performance results. Building characteristics were identified for collection in this process based on their applicability in comparative analysis, design guidance, and urban planning, as shown in literature. In particular, building characteristics and performance metrics were selected to describe the passive and active building systems, and the annual and dynamic hourly energy consumption results. The methodology lists the location of each metric in the eQUEST output file and outlines any necessary post-processing calculations.

The resulting database is designed to be used to undertake comparative analysis and generate design recommendations. The algorithm for this final phase has not been generated, however the key building characteristics and performance indicators have been identified and are discussed in detail, along with a strategy for facilitating comparative analysis. Specific database-development algorithms will be developed by others during the creation of the future online tool, since the data collection process is closely aligned with this software development.

4.0 Online Tool Structure

The algorithms and processes developed in this research project will be used to create an online screening and benchmarking tool for new buildings. The software development is outside the scope of this project, however the anticipated structure of the online tool is shown in Figure 3. The algorithm can be summarized as follows.

User Inputs – Upon initiating the tool, a user uploads the eQUEST input file (.inp) of their proposed building design, and identifies certain characteristics of the building (refer to Section 5). These user inputs are stored to inform the decision-making and calculations of later processes.

Baseline Creation – Two baseline buildings of comparison are automatically generated using the proposed building geometry, occupancy, and schedules – one meeting the requirements of ASHRAE 90.1-2010, and one meeting the requirements of the Ontario Building Code 2012 (refer to Section 6).

Program Screening – All necessary inputs to screen the proposed building against four programs are added to the relevant eQUEST input files. The tool then runs the three simulations – one proposed and two baseline models – and returns the performance of the proposed building in all four programs, automatically performing any required calculations, and generating the submission information (refer to Section 7).

Data Collection – Characteristics and energy performance results of the proposed building simulation will be extracted from the eQUEST output file and saved into a database of new buildings in Toronto (refer to Section 8). The data will be marked as 'design development' or 'completed building' prior to storage in the database, based on the user-input classification.

Tool Outputs – Two possible tool outputs are available, depending on the stage of the building project (refer to Section 8).

1. A project in design development stage will receive the preliminary estimated performance of the proposed building in each of the programs, as well as the building's performance compared to the database of new building models. The user can select what comparative analysis parameters will be used for this benchmarking output. The performance of both baseline models will also be displayed in the comparative analysis, however the baseline performance results will not be stored in the database.

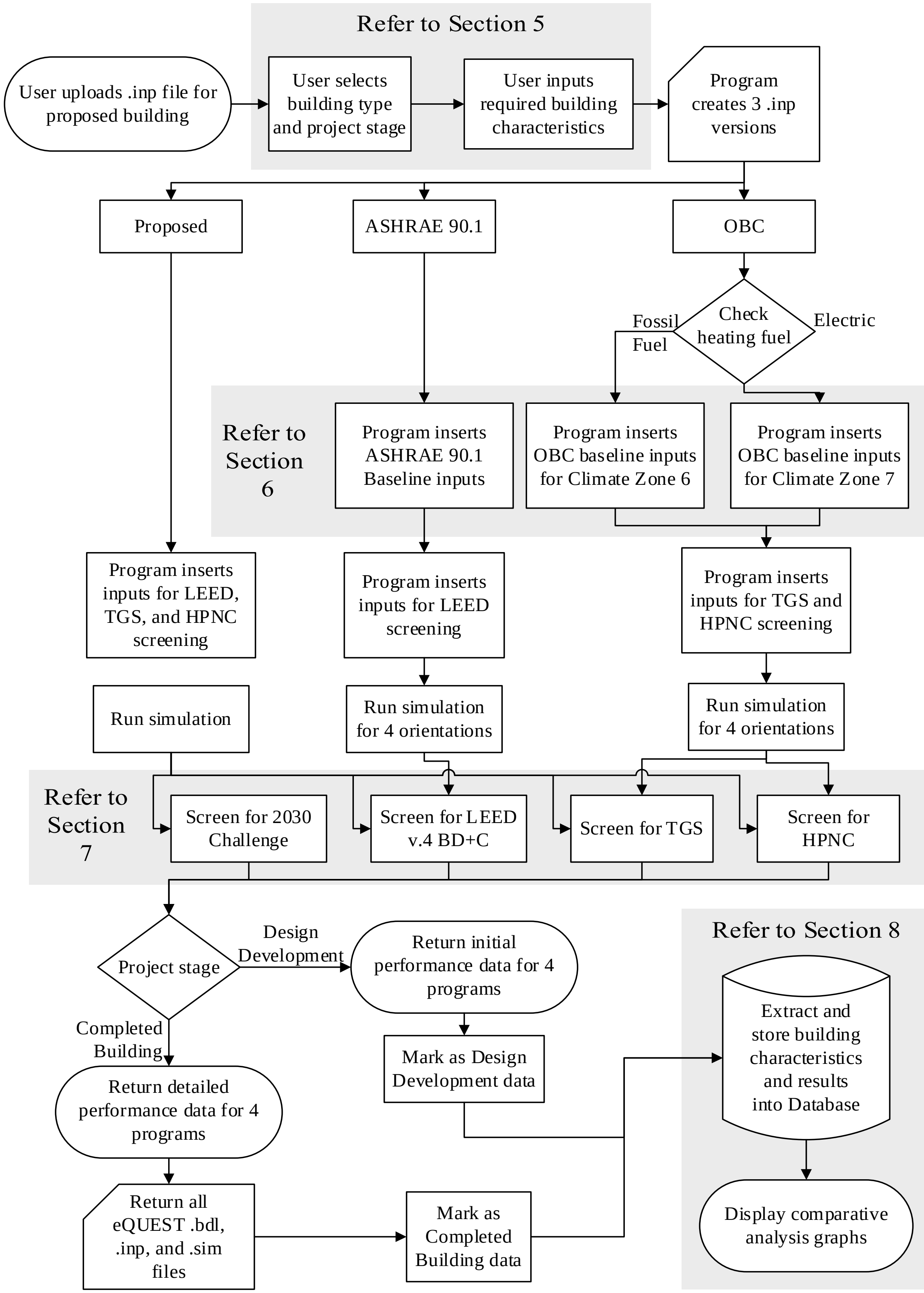


Figure 3 – Online Tool Flow Chart

2. When run for a completed building, in addition to the above comparative analysis and benchmarking output, the tool will return all of the generated eQUEST input and output files, and detailed data outlining the proposed building's estimated performance under the four screening programs. This data is presented in a similar format as is required by the submission documentation of each program.

The relevance of this online tool can be expanded through collaboration with program administrators: the Canadian Green Building Council (CaGBC) for LEED v4 BD+C, City of Toronto for TGS, and Toronto Hydro for HPNC. At present, the methodology outlined in this investigation provides the user with the required information for their manual completion of program application documentation. Partnership with the program administrators could mean that the online tool directly outputs the documentation needed for application to each program.

5.0 User Inputs

This section describes the information that must be manually input by the user at the start of the screening and benchmarking process.

After initiating the tool, the user must upload the eQUEST input file of their proposed building design. The Building Description Language input file (.inp) is used for this purpose. No weather data is needed, since this tool is specifically for buildings in Toronto and will automatically input the appropriate weather file.

If the building has not previously been analysed by the tool, it will be assigned a unique identification number. This identifier will allow the user to revisit the online tool as the design process progresses and see how the comparative building performance changes. It also adds confidentiality, since details that can be used to identify the building can be stored separately from the building performance results, linked by the identification number. These private details will never be displayed by the tool, but may be used in future planning or energy mapping activities. The user will be asked to input the identification number if they are re-uploading a building into the tool, to avoid duplication within the database. This strategy is intended to add confidentiality to the process and encourage open sharing of data.

There are some building characteristics that are not clearly indicated by the eQUEST input file, and that the user is required to input manually upon uploading the proposed building to the tool. The selections and inputs made by the user will be used to develop the baseline buildings and perform the program screening; future references in this report to "user-input" parameters are calling upon the inputs made at this stage in the tool function. The user-inputs are summarized in Table 3.

The user is required to assign a building activity type to their proposed design by selecting the most appropriate description from a list. This building type is used by the tool to assign the correct building envelope, lighting, and HVAC characteristics to the baseline input files, and during the screening process. The available building types, listed in Table 4, are taken from the U.S. Energy Information Administration *Commercial Building Energy Use Survey* (CBECS) (Architecture 2030 n.d.). These categories have been selected because they are used in the 2030 Challenge Targets for the United States (Architecture 2030 2007) as well as in the EPA *Target Finder* tool (US EPA n.d.). Further, the CBECS list is closely aligned with the building type definitions in the ASHRAE Standards 90.1 and 62.1, which are used for the tool's baseline input creation.

Although Canadian building activity types are defined in detail by the Natural Resources Canada *Comprehensive Energy Use Database*, only ten building types have been assigned 2030 Challenge targets (Architecture 2030 n.d). It is anticipated that 2030 Challenge targets will be assigned to additional Canadian building activity types in the future, and that these building types will resemble the CBECS and *Target Finder* categories. As more building activity types are assigned Canadian 2030 Challenge targets, the building types used by this screening tool can be updated to match the Canadian context.

Table 3 – User Input Summary

Input	Type	Justification
Proposed building energy model	Uploaded .inp file	Chosen source of building information
Identification Number	Value	Links a proposed building to former iterations
Postal Code	Value	Provides general location of building
Year of Completion	Value	Used for 2030 screening and data normalization
Project Stage	Drop-down Menu	Distinguishes design development from completed building
Building Activity Type	Drop-down Menu	Used for baseline creation and data normalization
Number of Floors	Value	Used for baseline creation, can be difficult to extract with certainty
Heating Fuel	Drop-down Menu	Used for baseline creation, can be difficult to extract with certainty
Building Cooling?	Drop-down Menu	Used for baseline creation
On-Site Renewable Electricity Generation	Value	Used for program screening, not calculated in eQUEST
Off-Site Renewable Electricity Generation	Value	Used for program screening
On-Site Renewable Electricity Price	Value	Used for program screening, varies by contract

Table 4 – Building Activity Types

Building Activity Category	Subdivision
Education	General
	K-12 School
	College/university (campus level)
Food Sales	General
	Grocery store/food market
	Convenience store (w/ or w/out gas station)
Food Service	General
	Restaurant/cafeteria
	Fast food
Inpatient Health Care (hospital)	General
Lodging	General
	Dormitory/fraternity/sorority
	Hotel, motel or inn
Mall (strip mall and enclosed)	General
Nursing/assisted living	General
Office	General
Outpatient and health care	General
	Clinic/other outpatient health
	Medical office
Public assembly	General
	Entertainment/culture
	Library
	Recreation
	Social/meeting
Public order and safety	General
	Fire/police station
Service (vehicle repair/service, postal service)	General
Storage/shipping/nonrefrigerated warehouse	General
	Non-refrigerated warehouse/distribution center
Refrigerated warehouse	General
Religious worship	General
Retail store (non-mall stores, vehicle dealerships)	N/A
Other	N/A

Additional user inputs include the number of floors in the building, and selection of the heating fuel used by the proposed building. While it is possible to determine both of these characteristics through careful examination of the eQUEST files, including them as user-input values ensures that no errors are made. Any renewable energy generation, from both on-site systems and purchased off-site credits, must be calculated outside of eQUEST and manually input by the user.

Finally, the user will be asked to input details, such as whether the project is in design development stage or is a completed building design, to assist in its integration into the database of new buildings. Users who select the completed building option will also be asked to input the year of completion. The general location of their building is indicated by inputting the proposed building's six-digit postal code.

6.0 Baseline Creation

This section describes the development of a methodology for automating baseline building model creation based on the eQUEST Building Description Language input (.inp) file for a proposed new building in Toronto. This baseline building model is needed to screen for the performance of a proposed building in three of the four selected programs: LEED v4 BD+C uses the American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2010 as the reference standard for its baseline comparison; TGS and HPNC assess the proposed building design based on its energy performance over the 2012 Ontario Building Code. The 2030 Challenge assesses a building's energy use intensity compared with the program's stated targets, so no baseline comparison is required.

Although Sections 6.1 and 6.2 describe the automated creation of baseline simulation inputs, the output should not be considered a complete and final baseline model. Unique characteristics of the proposed building design may not be captured accurately by this generic and automated approach. As such, it is the responsibility of the qualified energy modeller to review the model inputs and results, revising as necessary to ensure that they match the proposed building's specific characteristics and demonstrate an accurate estimation of the building's annual energy consumption.

Please note that in this document, references to external appendices and tables are made using *italicized* lettering, whereas my own appendices and tables are referenced in normal typeface.

6.1 ASHRAE Standard 90.1-2010 Baseline

ANSI/ASHRAE/IES Standard 90.1-2010, the "*Energy Standard for Buildings Except Low-Rise Residential Buildings*" ("ASHRAE 90.1") (ASHRAE 2010) is used as the reference standard for the LEED v4 Building Design and Construction (BD+C) program (U.S. Green Building Council 2013).

Within the ASHRAE 90.1, *Normative Appendix G* is used to assess the performance of a proposed building design, by defining the characteristics of a baseline building. Performance improvement is quantified using the following equation:

$$Improvement\ (\%) = 100 \times \frac{(Performance_{Baseline} - Performance_{Proposed})}{Performance_{Baseline}}$$

The requirements of *Appendix G* were used to develop a set of inputs that can be applied to the eQUEST input file of a proposed building. These inputs, and the process for applying them to a proposed input file, are found in Appendix A and Appendix B. Sections 6.1.1 to 6.1.4 describe the methodology used to develop the inputs for Building Envelope, Lighting, Heating Ventilation and Air Conditioning (HVAC) Systems, and Service Hot-Water Systems, respectively.

6.1.1 Building Envelope

<u>Orientation</u>

The baseline building is required to be modelled in the orientation of the proposed building and after rotating by 90, 180, and 270 degrees. The baseline building performance is an average of these four simulations.

<u>Opaque Assemblies</u>

Appendix G specifies that baseline opaque building envelope assemblies should be simulated as lightweight assembly types, designed to match the maximum U-value requirements of ASHRAE 90.1 *Section 5.5*. These lightweight assemblies are: (1) roof with insulation entirely above the deck; (2) steel-framed above-grade walls; (3) steel-joist exterior floors; (4) unheated slab-on-grade; and (5) opaque doors to match the proposed design. For the purposes of this project, all opaque doors are simulated using the requirements for swinging doors.

The assemblies were further defined using ASHRAE 90.1 *Normative Appendix A*, which defines a base assembly for each building envelope component, including the R-value of each material layer. The *Appendix* then defines the R-value of thermal insulation required to achieve different overall U-Values based on differing construction factors such as framing type and depth.

For this project, Toronto is the target climate, so the maximum U-value for each assembly was defined by *Table 5.5-6: Building Envelope Requirements for Climate Zone 6 (A,B)*. When this maximum U-value did not appear on the tables in *Appendix A*, linear interpolation was used to determine the required R-value of thermal insulation.

Using this process, an assembly was defined in detail for each opaque building envelope component, and for three building classifications: nonresidential, residential, and semiheated. Table 5 outlines the base assembly for each opaque building component and building classification.

Table 5 - Opaque Building Envelope Component Assembly Requirements (ASHRAE 2010)

Opaque Envelope Component		**Nonresidential**	**Residential**	**Semiheated**
Roofs – Insulation Entirely above Deck				
	Maximum U-value (W/m²K)	U-0.273	U-0.273	U-0.527
	Assembly Layers (m²K/W)	R-3.47 Continuous insulation R-0 Metal deck R-0.11 Interior air film heat flow up	R-3.47 Continuous insulation R-0 Metal deck R-0.11 Interior air film heat flow up	R-1.81 Continuous insulation[a] R-0 Metal deck R-0.11 Interior air film heat flow up
Walls, Above-Grade – Steel-Framed				
	Maximum U-value (W/m²K)	U-0.365	U-0.365	U-0.705
	Assembly Layers (m²K/W)	R-0.01 Stucco R-0.10 16 mm Gypsum board R-1.26 Continuous insulation[a] R-1.1 Cavity insulation, effective R-value R-0.10 16 mm Gypsum board R-0.12 Interior air film	R-0.01 Stucco R-0.10 16 mm Gypsum board R-1.26 Continuous insulation[a] R-1.1 Cavity insulation, effective R-value R-0.10 16 mm Gypsum board R-0.12 Interior air film	R-0.01 Stucco R-0.10 16 mm Gypsum board R-0.91 Continuous insulation[a] R-0.10 16 mm Gypsum board R-0.12 Interior air film
Floors – Steel-Joist				
	Maximum U-value (W/m²K)	U-0.214	U-0.183	U-0.296
	Assembly Layers (m²K/W)	(from bottom to top) R-0.08 Semi-exterior air film R-0 Metal deck R-4.16 Continuous insulation R-0.04 102 mm Concrete R-0.22 Carpet and pad R-0.16 Interior air film heat flow down	(from bottom to top) R-0.08 Semi-exterior air film R-0 Metal deck R-4.91 Continuous insulation R-0.04 102 mm Concrete R-0.22 Carpet and pad R-0.16 Interior air film heat flow down	(from bottom to top) R-0.08 Semi-exterior air film R-0 Metal deck R-2.95 Continuous insulation R-0.04 102 mm Concrete R-0.22 Carpet and pad R-0.16 Interior air film heat flow down

Table 5, cont'd – Opaque Building Envelope Component Assembly Requirements (ASHRAE 2010)

Opaque Envelope Component		**Nonresidential**	**Residential**	**Semiheated**
Walls, Below-Grade – Below-Grade Wall				
	Maximum C-factor[b] (W/m^2K)	C-0.678	C-0.678	C-6.473
	Assembly Layers (m^2K/W)	R-1.33 Continuous insulation 200 mm Medium-weight concrete block R-0.08 13 mm Gypsum board	R-1.33 Continuous insulation 200 mm Medium-weight concrete block R-0.08 13 mm Gypsum board	200 mm Medium-weight concrete block
Slab-On-Grade Floors – Unheated				
	Maximum F-factor[c] (W/m^2K)	F-0.935	F-0.900	F-1.264
	Assembly Layers	150 mm Concrete 600 mm Vertical Insulation Soil, 1.30 W/m^2K	150 mm Concrete 600 mm Vertical Insulation Soil, 1.30 W/m^2K	150 mm Concrete 600 mm Vertical Insulation Soil, 1.30 W/m^2K
Opaque Doors – Swinging				
	Maximum U-value (W/m^2K)	U-3.975	U-2.839	U-3.975

Notes for Table 5

[a]Thermal resistance adjusted to correct for discrepancy when entered in eQUEST; refer to Table 6 for adjusted R-values

[b]ASHRAE 90.1 defines C-factor as thermal conductance through a material or construction, using the units W/m^2K, and notes that it does not consider soil or air films as part of the construction (ASHRAE 2010)

[c]ASHRAE 90.1 defines F-factor as "the perimeter heat loss factor for slab-on-grade floors," using the units W/mK (ASHRAE 2010)

Each of these assemblies were created in eQUEST as follows:

1. First, a new material was created with the thermal resistance dictated by *Appendix A*.
2. Next, a new layer was created, using materials as closely aligned with the *Appendix A* base assemblies as possible. Where necessary, the characteristics of the eQUEST library materials were adjusted to match the R-values outlined by *Appendix A* for the base assembly. The interior air film, defined by *Appendix A*, was also assigned to the layer.
3. Finally, a new construction was created, using the new layer. The overall U-value is calculated in eQUEST at the construction-level; this calculated U-value was compared to the maximum U-value, required by *Table 5.5-6*. Any discrepancy between the two was corrected by adjusting the thermal resistance of the new material in eQUEST, as listed in Table 6. The cause for these discrepancies is not known at this time.
4. Opaque door constructions were created using the simplified *U-VALUE* method, following the assembly maximum U-value described in *Table 5.5-6*.

Table 6 – Adjusted Envelope Thermal Resistance Values: ASHRAE Baseline

Envelope Component – Building Type	**ASHRAE R-value (m^2K/W)**	**Adjusted eQUEST R-value (m^2K/W)**
Roofs – Semiheated	1.81	1.75
Walls, Above Grade – Nonresidential	1.26	1.34
Walls, Above Grade – Residential	1.26	1.34
Walls, Above Grade – Semiheated	0.91	1.09

The eQUEST simulation process is unable to account for thermal transfer from the ground to the building, without simplification. As such, the effect of heat transfer on exposed perimeter of underground surfaces – slab-on-grade and below-grade walls - is simulated following the best-practice strategy described by Winkelman (Winkelmann 2002). An effective thermal resistance is calculated using the equation:

$$R_{eff} = Area/(F\text{-}factor \times Exposed\ Perimeter)$$

This effective thermal resistance is then simulated in eQUEST by modelling a fictitious insulation layer, separated from the underground surface by 0.3 m (12 inches) of soil. The thermal resistance of this fictitious layer is calculated to ensure that the overall R-value for the construction is equal to the effective thermal resistance calculated above.

$$R_{fic} = R_{eff} - R_{underground\ surface} - R_{soil}$$

The process to determine the R-value of the fictitious layer in the proposed building is described in Appendix B, with calculations in Appendix A. The developed process assigns fictitious insulation and soil layers to the underground surface that is identified as being adjacent to the open air – that has an exposed perimeter. Note that this method assumes that the heat transfer through non-exposed areas of the underground surface are negligible, so the thermal resistance of non-exposed underground surfaces is set to a large value.

The detailed eQUEST inputs created through the process described above are provided in Appendix A of this report.

<u>Fenestration</u>

ASHRAE 90.1 *Normative Appendix G* requires vertical fenestration to be distributed on each face of the building in the same proportion as the proposed building design, however the area of vertical fenestration must not be greater than 40% of the gross above-grade wall area. The fenestration is required to meet the maximum U-values and Solar Heat Gain Coefficient (SHGC) defined in *Table 5.5-6*.

The process for identifying whether any building has a window-to-wall ratio (WWR) which exceeds 40% is outlined in Appendix B of this report. For any building with WWR greater than 40%, the window area is reduced proportionally on each face by reducing the width of all windows by the same factor.

$$Window\ Width_{Baseline} = \frac{0.4}{WWR_{Proposed}} \times Window\ Width_{Proposed}$$

A similar process was used to limit the area of the skylights to a maximum of 5% of the gross roof area of the building, as required by *Appendix G*. Any roof that is identified as having a total skylight area greater than 5% will have its skylight area reduced proportionally by reducing the width of each skylight in the roof.

$$Skylight\ Width_{Baseline} = \frac{0.05}{Skylight\ Area_{Proposed}} \times Skylight\ Width_{Proposed}$$

For the purposes of this project, all vertical fenestration is assumed to be metal framed, with generic purpose. On *Table 5.5-6*, this is categorized as "Vertical Glazing, 0%-40% of Wall – Metal framing (all other)". All skylights are assumed to fall under the category of "Skylight without Curb, All, % of Roof" on *Table 5.5-6*. Table 7, below outlines the maximum U-value and SHGC of the baseline fenestration elements for each building classification.

Table 7 – Baseline Fenestration Requirements (ASHRAE 2010)

Fenestration Element		**Nonresidential**	**Residential**	**Semiheated**
Vertical Glazing, 0%-40% of Wall – Metal framing (all others)				
	Maximum U-value (W/m^2K)	U-3.12	U-3.12	U-3.69
	Assembly Maximum SHGC	SHGC-0.40	SHGC-0.40	No Requirement
Skylight without Curb, All – 0%-2.0% of Roof				
	Maximum U-value (W/m^2K)	U-3.92	U-3.29	U-7.72
	Assembly Maximum SHGC	0.49	0.49	No Requirement
Skylight without Curb, All – 2.1%-5.0% of Roof				
	Maximum U-value (W/m^2K)	U-3.92	U-3.29	U-7.72
	Assembly Maximum SHGC	0.49	0.39	No Requirement

The eQUEST Glass Library was used to develop the inputs for vertical glazing. After identifying the required maximum U-value and SHGC from *Table 5.5-6*, the eQUEST Glass Library was searched to determine the existing *Glass Type Code* with characteristics which most closely resemble the requirements. Selection of the *Glass Type Code* was based solely on characteristics, and does not imply endorsement of any specific manufacturer or product.

Skylight inputs were created using the *Shading Coefficient* method. Shading coefficient is calculated based on the SHGC as follows:

$$Shading\ Coefficient = \frac{SHGC}{0.87}$$

Glass conductance was determined using the DOE-2 Reference Manual Volume 2: Dictionary, Table 10. Linear interpolation was used to determine the glass conductance for each U-value specified by *Table 5.5-6*, using the values for a 7.5 mph wind speed.

The selected *Glass Type Codes* and detailed eQUEST inputs created through the processes described above are provided in Appendix A of this report. Appendix B details the decision-making and implementation algorithm needed to assign these inputs to the baseline building.

Air Infiltration

The ASHRAE 90.1 requirement for minimum envelope air tightness is given as 0.2 L/s-m^2 of envelope surface area, when tested at 75 Pa. To be input into eQUEST, this requirement must be converted to match the measurement method: cfm/ft^2 of floor area with no pressurization.

Using the comparative results from Gowri, *et al*. (Gowri, Winiarski and Jarnagin 2009), a correlation is found between building infiltration rate per unit of wall area and infiltration flow rate per unit of floor area: a conversion rate of 0.316 cfm/ft^2 of floor area per cfm/ft^2 of exterior wall area, assuming equal distribution of building-level air change in all zones. Using this factor, the eQUEST input infiltration flow rate (I_{eQUEST}) can be calculated:

$$I_{eQUEST} = \frac{0.2\,L}{s \cdot {m^2}_{envelope}} \times \frac{2.119\,cfm}{1\,L/s} \times \frac{1\,m^2}{10.76\,ft^2} \times \frac{0.316\,\frac{cfm}{{ft^2}_{floor}}}{1\,\frac{cfm}{{ft^2}_{envelope}}} = 0.0124\;\frac{cfm}{{ft^2}_{floor}}$$

This input can then be applied to the baseline input file by the infiltration method of *Air Change* to all spaces, and assigning the value of 0.0124 to the *Infiltration Flow per Area* input. This process is further detailed in Appendix B.

6.1.2 Lighting

ASHRAE 90.1 *Normative Appendix G* requires that the lighting power density (LPD) of the baseline building be assigned in the same fashion as the proposed building, using either the building area or space-by-space methods, as outlined in ASHRAE 90.1 *Section 9.2*. The building area method applies the same LPD to the whole building, based on the building type. In contrast, the space-by-space method tailors the LPD to the different space types within the building.

The inputs used for the baseline building of reference are defined differently for these two LPD assignment methods. To distinguish between the methods, the *Lighting Power per Area* input is examined for each space in the eQUEST model. If the input value is the same for every space in the model, the building area method is assumed to have been used in the proposed model and is used to assign the baseline LPD. When the input varies among the spaces in the model, the space-by-space method is used.

For the building area method, the building types available for selection by the user (see Section 5.0) have been compared to the Building Area Types identified in ASHRAE 90.1 *Table 9.5.1*, and correlations established. The LPD can be applied to the whole building based on the user-selected building type. For the space-by-space method, the eQUEST Activity Descriptions are compared to the Common Space Types identified in ASHRAE 90.1 *Table 9.6.1*, to establish correlations. The LPD can then be applied to each space based on the activity description defined in the proposed building input file.

No task lighting fixtures or automatic controls, including daylighting controls, are included in the baseline building, and the fixture-type is assigned as "suspended, surface mounted or recessed/non-vented fluorescent or HID" (Lawrence Berkeley National Laboratory 2016).

A full list of the eQUEST lighting inputs, and the process for applying them to the baseline are detailed in Appendix A and Appendix B. These inputs were developed by designing a baseline lighting system which complies with the requirements of *Normative Appendix G*.

6.1.3 HVAC Systems

ASHRAE 90.1 *Normative Appendix G* identifies ten possible heating, ventilation and air conditioning (HVAC) system types to be used by the baseline building, assigned depending on the building type, number of floors, floor area, and heating energy source. The components and characteristics of each HVAC system are outlined, as well as requirements that all systems must meet. The system types and components are shown in Table 8 and Table 9.

The requirements outlined by *Appendix G* can be divided into two groups: generic HVAC system requirements, and system-specific HVAC requirements. Some design conditions, such as space temperature setpoints, are not detailed by ASHRAE 90.1, and thus are assumed to be the same in the baseline and proposed buildings.

<u>Generic HVAC System Requirements</u>

The heating and cooling equipment for all baseline HVAC systems must be sized to meet the 99.6% design-day weather conditions, and be oversized by 25% and 15%, respectively. These design-day characteristics are given in ASHRAE 90.1 *Normative Appendix D* and can be specified in eQUEST, in addition to selecting a weather file to match the Toronto climate.

The ventilation design of the baseline building is required to match that of the proposed building, but cannot exceed the outdoor air intake flow rates prescribed by ANSI/ASHRAE

Standard 62.1-2013 "*Ventilation for Acceptable Indoor Air Quality*" ("ASHRAE 62.1"). If the proposed outdoor air flow rates do exceed ASHRAE 62.1 requirements, they must be reduced to match the Standard's values. To accomplish this, the eQUEST activity description for each space is compared to the Occupancy Categories identified in ASHRAE 62.1 *Section 6.2*, and a correlation is established. The ASHRAE 62.1 minimum outdoor air flow rate for each space can then be compared to the eQUEST outdoor air flow rate inputs of the proposed building, and the values adjusted as required.

Appendix G also states that when the proposed building is designed with enhanced ventilation air distribution effectiveness ($E_Z > 1.0$), the baseline building should be modelled with standard effectiveness ($E_Z = 1.0$). This requirement has been omitted from the scope of this project.

Table 8 – Baseline HVAC Systems (ASHRAE 2010)

Building Type	**System Type**	
	Fossil Fuel Heating	**Electric Heating**
Residential	System 1 – Packaged terminal air conditioner (PTAC)	System 2 – Packaged terminal heat pump (PTHP)
Nonresidential AND 3 floors or less AND <2,300 m^2	System 3 – Packaged single zone with rooftop air conditioner (PSZ-AC)	System 4 – Packaged single zone with rooftop heat pump (PSZ-HP)
Nonresidential AND 4 or 5 floors and <2,300 m^2 OR 5 floors or less and 2,300 m^2 to 14,000 m^2	System 5 – Packaged rooftop Variable Air Volume (VAV) with reheat (PVAV with reheat)	System 6 – Packaged rooftop VAV with parallel fan power boxes and reheat (PVAV with PFP Boxes)
Nonresidential AND more than 5 floors OR >14,000 m^2	System 7 – VAV with reheat (VAV with reheat)	System 8 – VAV with parallel fan power boxes and reheat (VAV with PFP Boxes)
Heated Only Storage	System 9 – Heating and ventilation (HVSYS)	System 10 – Heating and ventilation (HVSYS)

For each system, the heating and cooling equipment is assigned as listed in Table 9 using minimum efficiency levels defined by ASHRAE 90.1 *Tables 6.8.1A-G*. These minimum efficiencies are assigned based on system type and size category. In this project, size category is defined as the baseline whole building peak heating and cooling loads, and is determined by running the baseline simulation in eQUEST.

Table 9 – Baseline HVAC System Components (ASHRAE 2010)

System Type	Fan Control	Cooling Type and Equipment	Heating Type and Equipment
1 – PTAC	Constant volume	Direct expansion – PTAC, Standard size	Hot-water fossil fuel boiler
2 – PTHP	Constant volume	Direct expansion – PTHP, Standard size	Electric heat pump – PTHP, Standard Size
3 – PSZ-AC	Constant Volume	Direct expansion – Air conditioning, Air cooled	Fossil fuel furnace
4 – PSZ-HP	Constant Volume	Direct expansion – Air cooled heat pump	Electric heat pump – Air cooled
5 – PVAV with reheat	VAV	Direct expansion – Air conditioning, Air cooled	Hot-water fossil fuel boiler
6 – PVAV with PFP Boxes	VAV	Direct expansion – Air conditioning, Air cooled	Electric resistance
7 – VAV with reheat	VAV	Chilled water – Water cooled chiller, electrically operated, varying compressor types	Hot water fossil fuel boiler
8 – VAV with PFP Boxes	VAV	Chilled water – Water cooled chiller, electrically operated, varying compressor types	Electric resistance
9 – HVSYS	Constant Volume	None	Fossil fuel furnace
10 - HVSYS	Constant Volume	None	Electric resistance

The minimum efficiency performance of electrical equipment is assigned in ASHRAE 90.1 as a coefficient of performance (COP) or energy efficiency ratio (EER), depending on the equipment type. These requirements are input into eQUEST using the following conversion to electric input ratio (EIR).

$$EIR = \frac{1}{Coefficient\ of\ Performance} = \frac{3.412}{Energy\ Efficiency\ Ratio}$$

The minimum efficiency performance of fossil fuel heating equipment is assigned as thermal efficiency in ASHRAE 90.1. This is converted to heat input ratio (HIR) when input into eQUEST.

$$HIR = \frac{1}{Thermal\ Efficiency}$$

In the Toronto climate, exhaust air energy recovery is required for all baseline building systems, depending on the supply air flow rate and percentage of outdoor air. A minimum enthalpy recovery effectiveness of 50% is required for the baseline building. The current version of eQUEST does not yet support the simulation of exhaust air energy recovery, however inputs have been defined in Appendix B under the expectation that this function will soon be integrated into the modelling software. These inputs were created using eQUEST commands from a previous version of the software.

System-specific HVAC Requirements

The decision-making process and eQUEST inputs determined for each HVAC system are detailed in Appendix B. These inputs were developed by designing a baseline HVAC system in eQUEST to match the requirements of each HVAC system identified by *Normative Appendix G*.

Outdoor air economizers are required for Systems 3 through 8, using a maximum outdoor dry-bulb temperature of 21°C (70°F). For Systems 1, 2, 9, and 10, the outdoor air flow is controlled in eQUEST as a fixed fraction, while Systems 3 through 8 control the outdoor air flow based on outdoor air temperature.

The design supply air flow rates for Systems 1 through 8 are based on a supply-air-to-room-air temperature differential of 11.1K (20°F) to achieve comfort conditions, or the required outdoor air flow rate, whichever is greater. To assign the baseline design air flow rate, these two values are calculated and compared for each space in the eQUEST model.

$$Supply\ Air\ Flow\ Rate_{System\ 1-8} = \frac{Peak\ Whole\text{-}Building\ Cooling\ Load}{1.02\,\frac{kg}{m^3} \times 1.2\,\frac{kJ}{kg} \times 11.1\ K} \times 1.15$$

$$Outdoor\ Air\ Flow\ Rate = Air\ Rate_{People} \times Occupancy_{Space} + Air\ Rate_{Area} \times Area_{Space}$$

A similar comparison is done to determine the design supply air flow rate for Systems 9 and 10, however the supply air flow rate is calculated using a temperature differential of 58.3K (105°F) between the supply air and the space temperature setpoint.

$$Supply\ Air\ Flow\ Rate_{System\ 9-10} = \frac{Peak\ Whole\text{-}Building\ Heating\ Load}{1.02\,\frac{kg}{m^3} \times 1.2\,\frac{kJ}{kg} \times 58.3\ K} \times 1.25$$

If a return fan is specified by the proposed building, and the baseline building uses Systems 1 through 8, a return fan is also added to the baseline building. The air flow rate is required to be the greater of: the baseline supply air flow rate less the minimum outdoor air flow rate, or 90% of the supply air flow rate. This comparison is made using the values calculated above.

The system fan power is defined by *Appendix G*. For Systems 1, 2, 9, and 10, the system fan power is defined as a factor of the supply air flow rate, as follows:

$$System\ Fan\ Power_{1,2,9,10} = Supply\ Air\ Flow\ Rate\ \times 0.64$$

For Systems 3 through 8, the system fan power is calculated using defined fan motor efficiencies. To determine the appropriate minimum fan motor efficiency, first the baseline fan motor input power ("Input kW") is calculated, using the supply air flow rate and pressure drop. In this project, the pressure drop is taken from the static pressure of the proposed building input file, using the assumption that the ventilation layout would remain consistent between baseline and proposed buildings.

$$System\ Fan\ Power_{3-8} = \frac{Input\ kW}{Fan\ Motor\ Efficiency}$$

The variable air volume (VAV) fan system requirements for baseline buildings using Systems 5 through 8 include part-load performance specifications. This project uses *Method 2* to define the fraction of full-load fan power using the part-load ratio (PLR) of current air flow rate vs. design air flow rate. This equation is defined in eQUEST, and the VAV fans are controlled using this curve.

$$Fan\ Power\ Fraction = 0.0013 + 1.470 \times PLR + 0.9506 \times PLR^2 + 0.0998 \times PLR^3$$

Systems 6 and 8 use parallel fan power boxes for HVAC distribution. This is simulated in eQUEST using the Power Induction Unit system-type, and Parallel Fan Power boxes as zone terminal units.

Appendix G lists several requirements for hot-water heating systems (used in Systems 1, 5, and 7) and chilled-water cooling systems (used in Systems 7 and 8). These include the type and number of boilers and/or chillers, supply water temperature setpoints, and temperature resets based on outdoor dry-bulb temperature. The inputs needed to implement these requirements in eQUEST are detailed in Appendix B.

Systems 7 and 8 use water-cooled chillers to provide cooling and axial fan closed-circuit cooling tower for heat rejection. The minimum efficiency requirements of the chillers are provided in *Table 6.8.1C* as a coefficient of full load performance, and an integrated part load value (IPLV).

There is no single eQUEST input for IPLV, rather the chillers must follow a defined part load performance curve. For this project, the default eQUEST chiller performance curve is used.

Two further simplifications have been made to the baseline buildings. First, it is assumed that buildings heated using fossil fuel all use natural gas, since oil heating is not commonly used in Toronto. Second, the requirements for purchased heat or chilled water have not been included in this algorithm. Future expansion of the online tool can include a wider range of heating and cooling energy sources.

Systems 1, 2, 9, and 10

The current version of eQUEST does not yet support the system types used in Systems 1, 2, 9 or 10 – Packaged Terminal Air Conditioning, Packaged Terminal Heat Pump, and Heating and Ventilating Systems. These system types were available in the previous version of eQUEST, and it is assumed that they will become available again in the future. Therefore, inputs have still been developed for these four systems using commands and keywords that were used in the earlier version of eQUEST. These inputs will need to be reviewed and may require updates to match future eQUEST versions.

6.1.4 Service Hot-Water Systems

ASHRAE 90.1 *Normative Appendix G* states that the service hot-water system of the baseline building must use the same energy source as the proposed building, but must be assigned the minimum equipment efficiency requirements, as outlined in ASHRAE 90.1 *Section 7.4.2*. Where a heat pump water heater is proposed, electric resistance is used as the energy source in the baseline building.

The prescribed efficiencies are taken from *Table 7.8* as shown in Table 10. The process for calculating and inserting these requirements into the eQUEST input file is detailed in Appendix B. The standby loss inputs are implemented by adjusting the heat loss coefficient (*TANK-UA*) of the water heater, using a temperature differential of 38.9°C (70°F) between the stored water and ambient air per the notes for *Table 7.8*. The size category (input rate) and heater volume are taken from the proposed building input file, under the assumption that the amount of domestic hot water consumed remains consistent, only the energy required to heat the water is altered.

Table 10 – Service Water Heating Performance Requirements (ASHRAE 2010)

Equipment Type	Size Category	Performance Required
Electric water heater	≤12 kW	$Minimum\ Energy\ Factor = 0.97 - 0.00035 \times Volume$
	>12 kW	$Maximum\ Standby\ Loss = 5.9 + 5.3\sqrt{Volume}$
Gas storage water heater	≤22.98 kW	$Minimum\ Energy\ Factor = 0.67 - 0.0005 \times Volume$
	>22.98 kW	Minimum Thermal Efficiency (E_t) = 80%, and $Maximum\ Standby\ Loss = \frac{Input\ Rate\ (Q)}{799} + 16.6\sqrt{Volume}$

6.2 Ontario Building Code 2012 Baseline

The Toronto Green Standard and the *High Performance New Construction* Incentive both use the Ontario Building Code requirements as a reference standard for their baseline buildings of comparison (Save On Energy 2016, Livegreen Toronto 2015).

Division B, Part 12 of *Ontario Regulation 322/12 (Building Code Act, 1992)* ("OBC") describes the building code requirements for Resource Conservation and Environmental Integrity. This includes specifying the minimum energy efficiency design. For the purposes of this report, the requirement under *Statement 12.2.1.2.(2).(b)* will be used to develop the baseline building inputs; this statement applies to buildings designed after December 31, 2016, and requires that the energy efficiency of buildings shall "conform to Division 1 and Division 3 or 5 of *MMAH Supplementary Standard SB-10*, 'Energy Efficiency Requirements'" (Ministry of Municipal Affairs and Housing 2012). This statement has been selected in an attempt to maintain relevance of the inputs, in recognition of the upcoming 2017 amendment to the OBC. Buildings falling under Part 9 of the OBC are excluded from the scope of this project.

Division 1 and Division 3 of *MMAH Supplementary Standard SB-10* ("SB-10") specify that buildings must meet the design requirements of ANSI/ASHRAE/IESNA Standard 90.1-2010, except as modified by Division 3, Chapter 2 (Ministry of Municipal Affairs and Housing 2012). These modifications are described below.

6.2.1 Building Envelope Requirements

The maximum U-values for opaque building envelope and fenestration components are specified and supersede the U-values listed in ASHRAE 90.1. For the Toronto climate, SB-10 *Table SB5.5-6* is used. When electric space heating is used, however, the envelope characteristics must comply with *SB5.5-7*, which increases the thermal insulation performance. The required values are shown in Table 11 and Table 12.

Table 11 – MMAH Supplementary Standard SB-10 Division 3 Table SB5.5-6 (Ministry of Municipal Affairs and Housing 2012)

Building Envelope Component	**Nonresidential**	**Residential**	**Semiheated**
	Assembly Maximum (W/m^2K)	**Assembly Maximum (W/m^2K)**	**Assembly Maximum (W/m^2K)**
Roofs – Insulation entirely above deck	U-0.18	U-0.18	U-0.36[a]
Walls, Above Grade – Steel Framed	U-0.31	U-0.31	U-0.48[a]
Walls, Below Grade – Below Grade Walls	C-0.52 W/m^2K	C-0.52 W/m^2K	C-0.68 W/m^2K
Floors – Steel Joist	U-0.18	U-0.13	U-0.21
Slab-on-Grade Floors – Unheated	F-0.90 W/mK	F-0.88 W/mK	F-0.93 W/mK
Opaque Doors – Swinging	U-2.27	U-2.27	U-3.41
Vertical Fenestration – Metal framing: all other	U-2.56 SHGC – 0.40	U-2.56 SHGC – 0.40	U-3.12 SHGC – N.R
Skylight without Curb, All – 0%-5.0%	U-2.56 SHGC – 0.46	U-2.56 SHGC – 0.39	U-7.72 SHGC – N.R.

[a]Thermal resistance adjusted to correct for discrepancy when entered in eQUEST; refer to Table 13 for adjusted R-values

Table 12 – MMAH Supplementary Standard SB-10 Division 3 Table SB5.5-7 (Ministry of Municipal Affairs and Housing 2012)

Building Envelope Component	**Nonresidential**	**Residential**	**Semiheated**
	Assembly Maximum (W/m^2K)	**Assembly Maximum (W/m^2K)**	**Assembly Maximum (W/m^2K)**
Roofs – Insulation entirely above deck	U-0.16	U-0.16	U-0.36[a]
Walls, Above Grade – Steel Framed	U-0.31	U-0.21	U-0.48[a]
Walls, Below Grade – Below Grade Walls	C-0.52 W/m^2K	C-0.42 W/m^2K	C-0.68 W/m^2K
Floors – Steel Joist	U-0.18	U-0.13	U-0.21
Slab-on-Grade Floors – Unheated	F-0.52 W/mK	F-0.52 W/mK	F-0.93 W/mK
Opaque Doors – Swinging	U-2.27	U-2.27	U-3.41

Vertical Fenestration – Metal framing: all other	U-1.99 SHGC - 0.45	U-1.99 SHGC – N.R	U-3.12 SHGC – N.R
Skylight without Curb, All – 0%-5.0%	U-2.56 SHGC – 0.46	U-2.56 SHGC – 0.46	U-7.72 SHGC – N.R

[a]Thermal resistance adjusted to correct for discrepancy when entered in eQUEST; refer to Table 13 for adjusted R-values

The eQUEST building envelope components developed in Section 6.1.1 were adapted to meet these requirements. These inputs are presented in detail in Appendix A. As described in Section 6.1.1, the eQUEST calculated U-value of each construction was compared to the requirements listed above; any discrepancies were corrected by altering the thermal resistance of the eQUEST inputs. The adjusted envelope thermal resistance values are listed in Table 13.

Table 13 – Adjusted Envelope Thermal Resistance Values: OBC Baseline

Envelope Component – Building Type	Applies to:	OBC R-value (m^2K/W)	Adjusted eQUEST R-value (m^2K/W)
Roofs – Semiheated	Table 11 and Table 12	2.60	2.61
Walls, Above Grade – Semiheated	Table 11 and Table 12	1.59	1.75

6.2.2 Electric Motors

The nominal minimum efficiency of electric motors is specified by *Supplementary Standard SB-10*. The application of this requirement is not considered within the scope of the current research, due to its limited application to most building energy models.

6.2.3 Baseline Creation

The process for creating a baseline based on the OBC very closely follows the process described in Section 6.1 and is listed in Appendix C. An additional step is required to examine the space heating fuel for differentiation between the two sets of building envelope requirements, discussed in Section 6.2.1.

6.3 Discussion of Automated Baseline Creation

The algorithms created in Sections 6.1 and 6.2, when implemented in the online tool, generate two separate baseline models, one each to comply with ASHRAE 90.1-2010 and OBC 2012. This is accomplished by identifying relevant eQUEST commands and keywords in the input file, and applying compliant input values, whether taken directly from each reference standard, or derived from the characteristics of the proposed building. Since these values are selected or calculated based on assumptions about the proposed building, the baseline models must be reviewed by an experienced energy modelling professional. The automated baseline process may encounter difficulty with complicated buildings, or those with unusual characteristics, such as swimming pools.

Generation of baseline models is an existing function of several energy simulation software, but is not implemented in a completely automated way. While EE4 does automatically develop a baseline building according to the requirements of the Model National Energy Code for Buildings (MNECB) 1997 requirements (NRCan 2008). Unfortunately, this function is no longer valuable: the software is outdated, and the reference standard has been superseded by the National Energy Code of Canada for Building (NECB) 2011. The function is under development in eQUEST, and its Canadian adaptation, CAN-QUEST, to automatically generate baseline buildings that are compliant with ASHRAE 90.1-2007 and NECB 2011, respectively. At the time of writing, full functionality of this feature has not been achieved in either software: the eQUEST manual describes the process as "semi-automatic" (Lawrence Berkeley National Laboratory 2016) analysis of compliance with LEED New Construction – which follows ASHRAE 90.1-2007 – requiring user adjustment; while the release notes for CAN-QUEST (NRCan 2016) list several modifications that must be input manually. Finally, in IES-VE, a baseline building that meets ASHRAE 90.1 requirements can be generated by activating the *PRM Navigator* and following a wizard-style series of guided user inputs (IES n.d.). While this approach simplifies the baseline creation process for the user, it is not completely automated and still requires good user-understanding of ASHRAE 90.1 *Appendix G*.

Only the baseline generation of EE4 can be considered truly automated. All other software applications, including the algorithms developed in this research, require at least detailed review by the user, if not manual adjustment of baseline building characteristics. In comparison with the existing options, the algorithms developed at this time are novel in two ways:

1. The process does not need to be completed in parallel with the creation of the proposed building model; rather the baseline buildings is generated from completed models.

2. The algorithms can be used to simultaneously generate two baseline buildings that comply with a) ASHRAE 90.1 and b) OBC 2012 from a single proposed building input file.

7.0 Program Screening

In this section, the energy performance requirements of the four programs are explored in detail and a methodology is presented for using eQUEST simulation files to evaluate the performance of a proposed building according to the requirements and evaluation rubric of each program. The screening is designed to provide the user with an estimate of the proposed building's performance in each program, as well as the inputs needed to complete the program submission documentation. Actual submission documentation will need to be manually completed by the user, after quality assurance checks have been performed on the simulation results.

All calculations and eQUEST inputs have been included in Appendix A.

7.1 LEED v4 BD+C

LEED v4 BD+C for New Construction measures the energy performance of proposed buildings in terms of energy cost savings compared to a baseline building designed to meet ASHRAE Standard 90.1-2010 *Normative Appendix G* (U.S. Green Building Council 2013). The Energy and Atmosphere Prerequisite: *Minimum Energy Performance* requires that the proposed building meet a minimum percentage improvement in energy cost of 5% above the baseline. This performance standard is required for any project looking to become certified under the LEED v4 BD+C rating system. With this prerequisite achieved, the Energy and Atmosphere Credit: *Optimize Energy Performance* awards LEED points to proposed buildings that achieve further percentage improvements in energy cost, with greater percentage improvement earning more points.

The percentage improvement is calculated using the following equation, detailed by ASHRAE 90.1 *Appendix G*:

$$Improvement\ (\%) = \frac{\left(Annual\ Energy\ Cost_{Baseline} - Annual\ Energy\ Cost_{Proposed}\right)}{Annual\ Energy\ Cost_{Baseline}} \times 100$$

Table 14 summarizes the available LEED v4 BD+C points that are achieved for incremental percentage improvement above the baseline energy cost. Two different point scales are identified for healthcare and school building activity types, which have slightly altered requirements in other LEED credits. Note that data centres also have altered requirements and are not included in the scope of this research.

Table 14 – LEED v4 BD+C Points for Percentage Improvement over Baseline (U.S. Green Building Council 2013)

<table>
<tr><th>% Savings Range</th><th>Points – Healthcare</th><th>Points – School</th><th>Points – All Other</th></tr>
<tr><td>0.0 – 4.9</td><td colspan="3">0</td></tr>
<tr><td>5.0 – 5.9</td><td colspan="3">Prerequisite Achieved</td></tr>
<tr><td>6.0 – 7.9</td><td>3</td><td>1</td><td>1</td></tr>
<tr><td>8.0 – 9.9</td><td>4</td><td>2</td><td>2</td></tr>
<tr><td>10.0 – 11.9</td><td>5</td><td>3</td><td>3</td></tr>
<tr><td>12.0 – 13.9</td><td>6</td><td>4</td><td>4</td></tr>
<tr><td>14.0 – 15.9</td><td>7</td><td>5</td><td>5</td></tr>
<tr><td>16.0 – 17.9</td><td>8</td><td>6</td><td>6</td></tr>
<tr><td>18.0 – 19.9</td><td>9</td><td>7</td><td>7</td></tr>
<tr><td>20.0 – 21.9</td><td>10</td><td>8</td><td>8</td></tr>
<tr><td>22.0 – 23.9</td><td>11</td><td>9</td><td>9</td></tr>
<tr><td>24.0 – 25.9</td><td>12</td><td>10</td><td>10</td></tr>
<tr><td>26.0 – 28.9</td><td>13</td><td>11</td><td>11</td></tr>
<tr><td>29.0 – 31.9</td><td>14</td><td>12</td><td>12</td></tr>
<tr><td>32.0 – 34.9</td><td>15</td><td>13</td><td>13</td></tr>
<tr><td>35.0 – 37.9</td><td>16</td><td>14</td><td>14</td></tr>
<tr><td>38.0 – 41.9</td><td>17</td><td>15</td><td>15</td></tr>
<tr><td>42.0 – 45.9</td><td>18</td><td>16</td><td rowspan="3">16</td></tr>
<tr><td>46.0 – 49.9</td><td>19</td><td>17</td></tr>
<tr><td>50.0 – 100.0</td><td>20</td><td>18</td></tr>
</table>

There are two other credits under the Energy and Atmosphere category that relate to the energy performance of a proposed building: *Demand Response*, and *Renewable Energy Production* (U.S. Green Building Council 2013), however evaluating the potential for a proposed building to achieve these two credits is not within the scope of this project.

Annual energy costs are determined using the rate structure of the proposed building's local utilities. For this project, which only considers the Toronto context, Toronto Hydro is assumed to be the electricity provider, and Enbridge Gas the provider of natural gas. Toronto Hydro has a number of electricity rate structures available for customers with different contracts and consumption profiles. These rate structures are time-of-use (TOU) rates, tiered rates, hourly spot pricing, and retailer rates. For simplicity, this report uses the hourly spot pricing rate structure, which assumes that the customer pays the wholesale electricity price and Global Adjustment electricity charge, based on the Hourly Ontario Energy Price (HOEP) (Toronto Hydro 2016). The IESO releases an annual summary of the electricity data for Ontario; in 2015, the weighted wholesale price of electricity was $0.0236/kWh, and the Global Adjustment rate was $0.0778, for a total average electricity cost of $0.1014/kWh (IESO 2016). This cost is used as the electricity charge for this screening, since an average for 2016 was not available at the time of this writing.

In addition to the electricity charge, customers of Toronto Hydro must pay monthly delivery and regulatory charges. The delivery charge rate structure for general service is divided into four tiers, depending on the monthly electricity demand of the building, and charges are assigned based on monthly electricity consumption (kWh), demand (kW) and apparent power (kVA) (Toronto Hydro 2016). The delivery and regulatory charges are made up of monthly flat rates and unit rates, which combine with the electricity charge to form the total marginal cost of electricity. The aggregated monthly costs for each tier are shown in Table 15 (Toronto Hydro 2016).

Table 15 – Toronto Hydro Electricity Costs

	<50 kW	**50 to 999 kW**	**1,000 to 4,999 kW**	**5,000 kW and above**
Monthly Flat Rates - $/month	39.75	68.81	837.09	3694.97
Monthly Unit Rates - $/kWh	0.15135	0.1074	0.1074	0.1074
Monthly Unit Rates - $/kW	0	5.8754	5.7566	6.4841
Monthly Unit Rates - $/kVA	0	6.947	5.3384	5.683

For natural gas, costs are assumed to follow Rate 6 of the Enbridge Gas *Large Volume Rates* structure (Enbridge Gas 2016). While there is only one monthly gas supply charge rate, the delivery charge is tiered based on the amount of natural gas that is purchased. There is a monthly flat rate charge of $70 for all customers. Table 16 lists the total monthly unit price at each tier of monthly natural gas consumption (Enbridge Gas 2016).

Table 16 – Enbridge Gas Natural Gas Costs

Amount of Gas Used in One Month	**Monthly Unit Rates ($/m^3)**
First 500 m^3	0.264459
Next 1,050 m^3	0.245649
Next 4,500 m^3	0.232477
Next 7,000 m^3	0.224013
Next 15,250 m^3	0.220253
Over 28,300 m^3	0.219309

A set of eQUEST inputs have been developed for the utility rate structures outlined above. These inputs, which can be found in Appendix A, are applied to both the proposed and baseline eQUEST models, to ensure consistency between the output values for annual energy cost. Note that there is no eQUEST input for monthly power demand charges ($/kVA), so the charges have been converted to energy demand ($/kW) using an assumed power factor of 0.8.

Under LEED v4 regulations, on-site renewable energy generation can contribute to the *Optimize Energy Performance* points of a proposed building, however the building design must meet the *Minimize Energy Performance* prerequisite 5% reduction without assistance from on-site energy generation (U.S. Green Building Council 2013). The generation potential of renewable energy systems is not calculated by eQUEST, so a net annual energy consumption is manually calculated based on the user-input annual on-site electricity generation values and sale price – refer to Section 5.0. With these values for energy generation, an annual net energy cost savings can be calculated and used to determine the number of *Optimize Energy Performance* points achieved, based on Table 14.

Collating the above information, the following process is used to screen a proposed building for its performance in LEED v4 BD+C for new construction:

1. Generate an ASHRAE Baseline model, following the process outlined in Section 6.1
2. Run the simulation for both the Proposed and ASHRAE Baseline model. Extract the peak annual electricity demand for each model from Report PS-E Energy End-Use Summary for all Electric Meters; use this value to select the appropriate electricity rate structure inputs for each model, from Appendix A.
3. Insert the selected Toronto Hydro and all Enbridge Gas meter and utility rate inputs into the input file of both the proposed building and the ASHRAE baseline. These inputs are found in Appendix A.
4. Run the eQUEST simulation for the proposed building, and for the ASHRAE baseline at all four orientations, per *Normative Appendix G*.
5. Extract the following information from each eQUEST output file (.sim):
    (a) Annual end-use electricity consumption (kWh) and peak demand (kW), found in Report PS-E – Energy End-Use Summary for Toronto Hydro electric meter

(b) Annual end-use natural gas consumption (therm) and peak demand (therm/hr), found in Report PS-E – Energy End-Use Summary for Enbridge fuel meter

(c) Total annual electricity consumption, natural gas consumption, and total building site energy consumption (MBtu, all), found in Report BEPS – Building Energy Performance

(d) Total annual electricity and natural gas charges, found in Report ES-D Energy Cost Summary

6. Average the four baseline orientations to determine one single baseline value for each of the above pieces of information
7. Calculate the percentage improvement of the proposed building total annual energy cost over the baseline building. This value must be greater than 5% in order for the proposed building to satisfy the *Minimum Energy Performance* prerequisite and be eligible for LEED certification.
8. Calculate the net annual energy consumption and net annual energy cost, using the user-input renewable energy generation values.
9. Calculate the percentage improvement of the proposed building net annual energy cost over the baseline building.
10. Determine the number of *Optimize Energy Performance* points, following the ranges outlined in Table 14, based on the user-input building type.

The information output from this screening process depends on the user-input for project stage – design development or completed building. For a design development-stage proposed building, the screening will tell the user whether the proposed building meets the prerequisite, return the percentage improvement in net annual energy cost, and the corresponding estimated number of LEED points. Screening of a completed building will further provide the user with the proposed and baseline eQUEST input and output files; the annual energy consumption and peak demand by end-use, fuel type, and building total; and the annual and net-annual energy cost savings. These values inform the "Performance Outputs" table of the LEED v4 Minimum Energy Performance Calculator.

The documentation required to apply for LEED certification includes the energy model input and output files for both the proposed and baseline buildings, as well as the completed

Minimum Energy Performance Calculator. Although the screening process provides input values for the calculator, it must be manually completed by the building designer, and can therefore be used as quality assurance for the automated baseline building model files.

7.2 2030 Challenge

The 2030 Challenge measures the success of a building's energy performance through comparison to a target site energy use intensity (EUI) (Architecture 2030 2015). This target EUI is tailored based on the building's climate zone, building type, and the year of construction.

The targets for Ontario are shown in Table 17. These targets are published by Architecture 2030, and are based on the *Comprehensive Energy Use Database* developed by the Natural Resources Canada Office of Energy Efficiency (NRCan 2016).

Table 17 – 2030 Challenge Target Site EUI for Ontario (Architecture 2030 n.d)

Commercial Space/ Building Type	Average Site EUI ($GJ/m^2/yr$)	2016 Target ($GJ/m^2/yr$)	2020 Target ($GJ/m^2/yr$)	2025 Target ($GJ/m^2/yr$)	2030 Target ($GJ/m^2/yr$)
Target Reduction		**70%**	**80%**	**90%**	**100%**
Wholesale Trade	1.853	0.556	0.371	0.185	0
Retail Trade	1.622	0.487	0.324	0.162	0
Transportation and Warehousing	1.398	0.419	0.280	0.140	0
Information and Cultural Industries	1.734	0.520	0.347	0.173	0
Offices	1.421	0.426	0.284	0.142	0
Educational Services	1.768	0.530	0.354	0.177	0
Healthcare and Social Assistance	2.038	0.611	0.408	0.204	0
Arts, Entertainment and Recreation	2.677	0.803	0.535	0.268	0
Accommodation and Food Services	2.597	0.779	0.519	0.260	0
Other Services	1.568	0.470	0.314	0.157	0

The building designer will be asked to select a building type which matches the proposed building, as they upload the eQUEST file, as described in Section 5.0. A relationship has been drawn between the building types listed in Table 17, and the available user-input building types.

These correlations are outlined in Appendix A, and can be used to look up the relevant Site EUI targets for the proposed building.

The following process can be used to screen a proposed building for its performance in meeting the 2030 Challenge targets:

1. Extract the Total Site EUI of the proposed building from the eQUEST output (.sim) file. This information can be found in the Building Energy Performance (BEPS) Report, and is given in kBtu/ft^2/year for both the gross area and net area of the building. As net area refers only to the conditioned spaces, the EUI for gross area should be used.
2. The Total Site EUI must be converted from imperial units to the metric units used in Table 17. The following calculation is used:

$$EUI\ [\frac{GJ}{m^2 \times yr}] = EUI\ [\frac{kBtu}{ft^2 \times yr}] \times \frac{1\ GJ}{947.8\ kBtu} \times \frac{10.8\ ft^2}{1\ m^2}$$

3. As discussed in Section 7.1, renewable energy generation is not calculated by eQUEST, and must be calculated separately by the designer. If an on-site renewable energy generation system is included in the building design, the user may enter the annual generation potential as an on-site energy generation intensity value (GJ/m^2/year). In addition, up to 20% of the building's Site EUI can be offset by off-site renewable energy generation (Architecture 2030 2015); if available, this value can also be input by the user. A Net Site EUI can be calculated, considering the energy generation intensity (EGI) as follows:

$$Net\ Site\ EUI = Site\ EUI_{Proposed} - (EGI_{On\text{-}Site} + EGI_{Off\text{-}Site})$$

   Note that if the user-input off-site energy generation intensity is greater than the allowable off-site renewable contribution, 20% of Proposed Site EUI, then the off-site renewable energy generation intensity is limited to the allowable value.

4. The success of the proposed building in achieving the 2030 Challenge targets can then be determined. The percent improvement over all three Target Site EUI values – for 2016, 2020, 2025, and 2030 – as well as over the Average Site EUI are calculated. A negative value indicates unsuccessful achievement of the 2030 Challenge target.

$$Improvement\ (\%) = \frac{\left(Site\ EUI_{Target} - Net\ Site\ EUI_{Proposed}\right)}{Site\ EUI_{Target}} \times 100$$

This process screens the proposed building against all of the listed Target Site EUI values for the appropriate building type, as well as against the Average Site EUI for Ontario. By doing so, a designer can see how the performance of their proposed building falls within the tiered reduction strategy of the 2030 Challenge, as well as how it compares to the existing building stock. The target reduction value for 2016 is included in this screening to demonstrate the performance level at which the proposed building should currently be designed.

7.3 Toronto Green Standard

The Toronto Green Standard (TGS) evaluates the energy performance of a proposed building in terms of percentage improvement of energy efficiency over a baseline building that complies with the Ontario Building Code (OBC).

Within the TGS *Version 2.0 for New Mid and High-Rise Residential and All Non-Residential Developments*, "Requirement GHG 1.1 – Energy Efficiency" dictates the minimum energy efficiency improvement for new buildings (Livegreen Toronto 2015). To reach Tier 1, which is mandatory for all new developments in Toronto, the proposed building must be designed to achieve a minimum of 15% energy efficiency improvement over the OBC. For new buildings targeting Tier 2 status, a minimum energy efficiency improvement of 25% over the OBC is required. On-site renewable energy generation is not included in the determination of the energy efficiency improvements, and the TGS requirements for renewable energy generation are not covered by this project.

While the compliance of a proposed building with TGS is measured solely on its percentage reduction of total annual energy consumption over the OBC baseline, the building designer must also submit an end-use breakdown of annual energy consumption, and winter and summer peak energy demand. The tool must therefore calculate these values in the screening process and output the final information output to match the *Energy Modelling Report Summary* form for the TGS application.

To calculate the seasonal peak energy demand of the proposed and baseline buildings, a report of the hourly energy consumption data must be requested in the eQUEST input file. The hourly data is returned separately for electricity and fuel. For this screening, peak winter demand is defined as the maximum total energy consumption – sum of electricity and fuel, in kW – in one hour between 00:00 November 1 and 23:59 April 30; peak summer demand is defined similarly, for the hours between 00:00 May 1 and 23:59 October 31. The inputs needed to generate the hourly report are detailed in Appendix A.

Screening the proposed building against the TGS requirements uses the OBC baseline generated as specified in Section 6.2, with the hourly energy consumption report requested in both the baseline and proposed inputs files, as described above.

The following steps are completed for each model to perform the screening, after running the simulation for both the proposed and OBC baseline building models.

1. From Report BEPU Building Utility Performance Report, extract the annual electrical and natural gas consumption by end-use and for the total building. The natural gas consumption must be converted from imperial units (therm) to metric equivalent units (ekWh).
2. Using the building total floor area, found in Report LS-C Building Peak Load Components, calculate the energy use intensity (EUI) for each end-use.
3. Extract the total building site EUI from Report BEPS Building Energy Performance; this value must be converted to metric units.
4. From the hourly results table, extract the hourly electrical and natural gas consumptions, and input into the table in Appendix A. Calculate hourly energy consumption by summing electrical and natural gas consumptions for each hour. Natural gas consumption must be converted to metric units (ekWh).
5. Find the winter demand peak as the maximum hourly energy consumption (kW) between November 1 and April 30.
    (a) Find the summer demand peak as the maximum hourly energy consumption (kW) between May 1 and October 31.

From this data, the seasonal energy demand savings, annual energy consumption savings, and percentage improvement over the baseline can be calculated for each end use and for the total building. Percentage improvement is calculated as:

$$Improvement\ (\%) = 1 - \frac{Energy\ Consumption_{Proposed}}{Energy\ Consumption_{Baseline}} \times 100$$

If the percentage improvement above the baseline is between 0% and 15%, the proposed building has not achieved the requirement of TGS. For percentage improvement between 15% and 25%, the building meets the mandatory Tier 1 minimum improvement requirement; improvement greater than 25% satisfies the requirement of TGS Tier 2.

The tool will return the values needed to complete the TGS *Energy Modelling Report Summary* if this is a *completed building*, or the percentage improvement and potential Tier level for a building in *design development stage*. A full energy model report is required for submission by the designer, and the OBC baseline inputs should be thoroughly reviewed to ensure accuracy.

The result of this screening does not guarantee that a building will successfully meet the TGS requirements, as only *Requirement GHG 1.1* is reviewed in this process. Nevertheless, the screening process indicates the potential for a proposed building to achieve Tier 2 status, or identify the potential need for improvement if Tier 1 is not achieved.

7.4 SaveOnEnergy High Performance New Construction (HPNC)

The SaveOnEnergy *High Performance New Construction* Incentive (HPNC) Custom Track awards financial incentives based on the energy performance improvement of a proposed building over a baseline building which meets the minimum requirements of the current Ontario Building Code (OBC). In contrast to the HPNC Engineered Track, the Custom Track is designed to reward building designers who find energy efficiency opportunities beyond the lighting and unitary air conditioning measures (Save On Energy 2016).

Using the custom track, the HPNC incentive is valued based on total energy demand reductions and reduction in annual energy consumption. For three tiers of annual energy performance improvement over the baseline, a dollar value is assigned separately for incremental improvements in energy demand, in $/kW, and energy consumption, in $/kWh. Both of these two incentive values are calculated based on simulated building energy performance, and the greater resulting dollar value is awarded to the project, up to a limit of 50% of the total project incremental costs. The incentive tiers and respective values are presented in Table 18, below (Save On Energy 2016).

Table 18 – HPNC Custom Track Available Incentives

Tier	Energy Performance Improvement[a]	Incentive Value (greater of the two)	
		Demand	Energy Consumption
Tier 1	0% - 25%	\$400/kW of Savings	\$0.05/kWh of Savings
Tier 2	25.5% - 50%	\$600/kW of Savings	\$0.075/kWh of Savings
Tier 3	50.5% and above	\$800/kW of Savings	\$0.10/kWh of Savings

[a]Energy performance improvement is rounded down to the nearest 0.5%

Energy performance improvement is calculated using annual energy consumption ("Energy") as shown in the following equation:

$$Improvement\ (\%) = \frac{\left(Energy_{Baseline} - Energy_{Proposed}\right)}{Energy_{Baseline}} \times 100$$

Energy demand savings are defined by this program as the largest difference between the baseline and proposed building energy consumptions, which occurs over a one-hour period on business days between June 1 and September 30, during the hours of 11am to 5pm (Save On Energy 2016). For the purposes of this project, 2016 is used as the simulation year so that the business hours can be identified. The process of requesting and gathering eQUEST hourly consumption results was described in Section 7.3.

HPNC uses the same OBC baseline as was used in TGS and, since there are no additional eQUEST inputs required, the following screening process is completed using the proposed and OBC baseline simulation output files that were generated in Section 7.3.

1. From the hourly results table, extract the hourly electrical and natural gas consumptions, and input into the table in Appendix A.
2. Calculate the total hour-by-hour energy consumption for both simulations by converting the natural gas consumption into ekWh and summing the two columns.
3. Determine the maximum peak demand savings (kW) by comparing the difference between baseline and proposed energy consumption at each hour
4. Calculate the percentage energy performance improvement, outlined above, and determine the appropriate incentive Tier for the proposed building
5. Calculate and compare the two potential incentive values, per Table 18, and return the greater of the two incentive dollar amounts

The result of this screening process may not represent the actual incentive potential of the proposed building as project costs are not considered thus the designer must manually complete the full HPNC worksheet for a more complete estimate of the incentive value of their project. This will also offer the opportunity for the designer to apply for additional Custom Track incentives, such as those for Modeller and Design Decision-Maker. Note also that since the incentive value is based on eQUEST simulation of the as-built conditions, screening performed on a design-stage model may not reflect the total incentive value of the proposed building.

7.5 Discussion of Automated Program Screening

The methodology and algorithms developed in this research are novel in their approach of simultaneous screening of a proposed building against many energy conservation programs. Overlaps have been identified in the data required for the different programs, which enable computational efficiency during the automated process. This efficiency is in large part enabled by the simultaneous automated generation of two different baseline buildings, a task that would be time consuming and not cost effective if performed manually.

8.0 Data Extraction and Analysis

This section details the extraction of simulated building data to create of a database for new and planned buildings in Toronto. This database will be used for the comparative analysis function of the online tool, allowing building designers to benchmark the characteristics of their building against other similar new buildings in Toronto. The data collected can also be used by urban planners, utilities and policy-makers as they look for opportunities to reduce the energy consumption and greenhouse gas emissions of Toronto's downtown core.

8.1 Data Collection

Data is extracted from the eQUEST simulation results of the proposed building, and is labelled as from a completed building or a building in design development before being stored in the database of new and planned buildings in Toronto (refer to Section 4.0). The unique identification number, which is assigned to each building on first use of the online tool, is used to link database entries for the same building in different stages of project completion.

Collected data falls into three categories of information: building and design characteristics, annual performance, and dynamic performance. The selected characteristics and their known impact on building energy use is discussed in the following subsections. All collected data is obtained from eleven eQUEST output reports (listed below). Table 19 through 22 indicate which report(s) contain the required data for each characteristic.

1. LS-C Building Peak Load Components
2. LS-D Building Monthly Loads Summary
3. LV-B Summary of Spaces Occurring in the Project
4. LV-D Details of Exterior Surfaces in the Project
5. LV-H Details of Windows Occurring in the Project
6. PV-A Plant Design Parameters
7. SV-A System Design Parameters
8. PS-E Energy End-Use Summary for all Electric and Fuel Meters
9. BEPS Building Energy Performance
10. BEPU Building Utility Performance
11. ES-D Energy Cost Summary

8.1.1 Building and Design Characteristics

General information about the building characteristics will be collected so that the buildings in the database can be sorted and compared with similar buildings, summarized in Table 19. Refer to Section 5.0 for more detail on the user-input characteristics. Further, these characteristics can be used to identify comparable buildings and filter the database information.

Table 19 – Building Characteristics

Characteristic	Information Source
Postal Code	Input by the user
Building Activity Type	Selected by the user from an available list
Gross Floor Area	Found in Report LS-C Building Peak Load Components
# Floors	Input by the user
Year of Completion	Input by the user

The passive system characteristics of a building are important factors when looking beyond energy conservation to consider the resilience of the building (Omrany and Marsono 2016). In particular, the passive thermal survivability – "the ability of a building to maintain an acceptable indoor temperature (shelter) when all active systems have failed" (Kesik 2015) – of the building can be explored through these passive system characteristics. Further, these characteristics can describe any wider trends among building designers in Toronto, and can help to direct policy and conservation program initiatives.

The selected characteristics are summarized in Table 20, as well as the source of each data point. It is worth acknowledging that the interaction between these characteristics is complex, and optimizing a building for one data point may mean reducing performance in another (Su 2011). The collection of these characteristics is not intended to imply a prescriptive approach to energy efficiency, rather a catalogue of topics for consideration, selected based on their relevance on energy consumption (Kesik 2015).

Characteristics of the building envelope have been demonstrated in literature to be strongly linked with building energy consumption. This is most clearly seen in the correlation between the thermal resistance value of the envelope system (U-value) and the heat loss through the envelope (Rodriguez-Ubinas, et al. 2014, Pacheco, Ordonez and Martinez 2012). In particular, glazing thermal resistance is one of the weakest thermal control points in a building (Pacheco, Ordonez and Martinez 2012). In a cold climate, such as Toronto, increased heat loss causes increased energy consumption in order to meet the comfort conditions during the winter. Due to this correlation, the thermal resistance of the proposed building is a valuable data point for extraction.

Other characteristics, such as solar heat gain coefficient (SHGC) and air infiltration rate can also contribute to increased energy consumption (Rodriguez-Ubinas, et al. 2014, Pacheco, Ordonez and Martinez 2012) and will be extracted into the database. Actual air infiltration rates of a new building depend almost entirely on the quality of construction, but are included in this data collection to offer an indication of the importance of air-tight building envelopes on energy consumption.

Many studies have been performed to establish a link between the geometry and architectural design of a building, and its energy consumption. In a cold climate, it has been shown that increased window-to-wall ratio (WWR) causes an increase in energy consumption (Su 2011), and that the best performance is found when using small windows in the north and large windows in the south (Susorova, et al. 2013). The whole building WWR will be extracted for the database, along with the WWR for each of the cardinal elevations. Capturing both metrics can demonstrate the flexibility of WWR among different facades, while maintaining a low overall ratio.

Similarly, the compactness of a building has been connected with energy efficiency: when the ratio between the building envelope surface area and the building volume increases, there is more opportunity for heat transfer through the envelope, and an increase in energy consumption can be seen (Su 2011, Pacheco, Ordonez and Martinez 2012).

Natural ventilation, thermal storage and daylighting performance are important passive system characteristics (Rodriguez-Ubinas, et al. 2014), but are not easily extracted from the eQUEST simulation files, and therefore will not be included in this research. Similarly, building orientation can be related to its energy efficiency (Pacheco, Ordonez and Martinez 2012), however this characteristic is often driven by site plan requirements in an urban setting such as Toronto, and has been omitted from this research.

Table 20 – Passive System Characteristics

Characteristic	Calculation	Information Source			
		LV-B	**LS-C**	**LV-D**	**LV-H**
Average U-value of Windows – Whole Building	N/A			*	
Average U-value of Walls – Whole Building					
Average U-value of Envelope – Whole Building					
Window-to-Wall Ratio (WWR) – North	$WWR = \frac{Area_{Window}}{Area_{Window+Wall}} \times 100$			*	
WWR – East					
WWR – South					
WWR – West					
WWR – All above-grade walls					
Skylight-to-Roof Ratio (SRR)	$SRR = \frac{Area_{Roof\ Window}}{Area_{Roof\ Window+Wall}} \times 100$			*	
Surface Area to Volume Ratio (S/V)	$S/V = \frac{Area_{Building\ Window+Wall}}{Volume_{Building}}$		*	*	
Average Solar Heat Gain Coefficient (SHGC) – Whole Building	$SHGC = Average(Glass\ Shading\ Coeff) \times 0.87$				*
Average Air Tightness	$Average\ Air\ Tightness = Average(\text{"}ACH\text{"}_{All\ spaces})$	*			

Building-specific variations on the active systems add complexity to the data collection process. HVAC plants and zonal distribution systems may need to be simplified for simulation in eQUEST, and the specific equipment layouts are not included in the model. Further, equipment efficiency is often driven by building code requirements and available technology rather than design decisions. Despite this, variations in active systems can significantly affect the energy consumption of a building – for example, the significant decrease in static pressure, and by extension, fan power, when using distributed heating and cooling approaches – and collecting characteristics about the system can be useful to building designers who are considering installing high performance equipment or deciding between different potential approaches.

A set of active system characteristics have been identified for collection and is listed in Table 21. If a characteristic is not available, for instance when the central plant of a building does not use the specified equipment, no value will be entered into the database. These characteristics fall into two categories: equipment efficiency and outdoor air design strategy.

Table 21 – Active System Characteristics

Characteristic	**Calculation**	**Information Source**	
		PV-A	**SV-A**
Boiler Efficiency	$Boiler\ Efficiency = \frac{1}{Boiler\ HIR} \times 100\%$	*	
Chiller Coefficient of Performance (COP)	$COP = \frac{1}{Chiller\ EIR}$	*	
Domestic Water Heater (DWH) Efficiency	$DWH\ Efficiency = \frac{1}{DWH\ HIR} \times 100\%$	*	
Domestic Water Heater COP (if applicable)	$COP = \frac{1}{DWH\ EIR}$	*	
Heat Pump (System) Heating EIR	$Heating\ EIR_{Total} = \frac{\sum Heating\ EIR_{Each\ System}}{\#\ of\ Systems}$		*
Heat Pump (System) Cooling EIR	$Cooling\ EIR_{Total} = \frac{\sum Cooling\ EIR_{Each\ System}}{\#\ of\ Systems}$		*
Average Static Pressure (SP) – Supply Fans	$SP_{Avg} = \frac{\sum(Capacity_{Supply} \times SP)_{EachSys}}{Capacity_{Supply,AllSys}} \times \frac{1in_{H2O}}{249Pa}$		*
Average Static Pressure (SP) – Return Fans	$SP_{Avg} = \frac{\sum(Capacity_{Return} \times SP)_{EachSys}}{Capacity_{Return,AllSys}} \times \frac{1in_{H2O}}{249Pa}$		*
Building Outside Air (OA) Flow Rate	$OA_{Total} = \sum OA_{Each\ System} \times \frac{1\ L/s}{2.119\ CFM}$		*
Building Supply Air (SA) Flow Rate	$SA_{Total} = \sum SA_{Each\ System} \times \frac{1\ L/s}{2.119\ CFM}$		*
Building Outside Air (OA) Ratio[a]	$OA\ Ratio = \frac{OA_{Total}}{SA_{Total}}$		*[a]

[a]Building Outside Air Ratio calculated using OA_{Total} and SA_{Total} as calculated above using values from Report SV-A

8.1.2 Annual Performance

The annual energy performance of a building is useful to know how the building design characteristics interact as a whole system in the context of the Toronto climate. Individual data points act as indicators for different parameters and points of interest in the building. This data can be used on a building-by-building scale through comparative analysis of the energy performance, or can be used in aggregate to estimate the total energy consumption of a group of buildings or community.

Energy performance metrics have been defined by the National Renewable Energy Lab (NREL) with the intention of standardizing the characterization of commercial buildings (Barley, et al. 2005). This procedure has been developed for assessment of existing buildings, however the identified metrics can be applied to simulated building energy performance to facilitate future comparison of measured and simulated performance data (Barley, et al. 2005). Therefore, this set of metrics has been used to inform the selection of annual energy performance characteristics for inclusion in the database. The selected characteristics are summarized in Table 22.

Building energy demand characteristics are collected subdivided by fuel type and end-use (Barley, et al. 2005). These metrics are valuable to utilities and urban energy planners because they indicate the peak loads on the utility grid and can identify opportunities for collaborative demand-side management among buildings in a micro-grid. Inclusion of space heating demand and space cooling demand metrics add valuable depth to the analysis as building designers move towards all-electric mechanical systems (TOcore Energy Working Group 2016).

In addition to extracting the total annual energy consumption, building energy use metrics are similarly collected and subdivided into consumption by end-use and fuel-type (Barley, et al. 2005). The end-use breakdown can demonstrate energy conservation opportunities to a building designer, if any end-use forms a larger percentage of the total energy use. Further, the annual heating and cooling design loads help contextualize the HVAC system efficiency, when compared to the total annual energy usage for space heating and cooling. Building annual electricity and natural gas usage metrics are needed for program screening, and can inform utilities of the overall consumption of each energy source.

Annual energy use intensity is a commonly used metric for benchmarking the energy consumption of buildings – for instance it is used for the 2030 Challenge program screening and required in the application for LEED v4 BD+C and TGS screenings (Architecture 2030 2015).

The user-input renewable electricity generation value can be also used to derive a net-annual energy use intensity for the building. These two metrics normalize the annual energy consumption by the building floor area, rendering them useful for comparison between buildings of different size.

Finally, energy cost metrics are extracted for storage in the database. These metrics are collected as total annual energy cost, annual electricity and natural gas costs, and virtual electricity and natural gas rates. Virtual rates for each fuel type can help the building owner to understand the impact of their energy consumption, which is particularly valuable when the energy charges use a tiered pricing scheme.

The data found in the eQUEST output file neither uses inconsistent units of measurement and both imperial and metric units are used in different eQUEST reports, however SI units are used for the database. In addition to identifying the annual energy performance characteristics to be extracted for storage in the database, and the source of information within eQUEST, Table 22 lists the unit in which each characteristic will be provided by eQUEST as well as the metric unit to be used for database storage. The conversion factors are listed below:

$$1\ kBtu/hr = 0.293\ kW \qquad 1\ kBtu/ft^2\text{-}yr = 3.152\ kWh/m^2\text{-}yr$$

$$1\ MBtu = 293\ ekWh \qquad 1\ Therm = 2.832\ m^3$$

$$1\ MBtu/hr = 293\ kW \qquad 1\ \$/Therm = 0.353\ \$/m^3$$

Annual energy charges are calculated by eQUEST using the utility rate structures that were described in Section 7.1 and input to facilitate the LEED program screening. No additional eQUEST inputs are required.

Notes for Table 22

[a]Total Annual Lighting Energy Usage calculated as:

$$Energy_{Total\ Lights} = Energy_{Lights} + Energy_{Task\ Lights}$$

[b]Annual Pumps, Fans and Auxiliary Energy Usage calculated as:

$$Energy_{Pumps,Fans,Aux} = Energy_{Pumps,Aux} + Energy_{Fans}$$

[c]Annual Net Energy Use Intensity calculated using Total Annual Site Energy Usage (Report BEPS) and user-input Annual On-site Renewable Energy Generation (Section 5.0):

$$Net\ EUI = \frac{Energy_{Total\ Site} - Energy_{Renewable}}{Gross\ Floor\ Area}$$

Table 22 – Building Annual Performance Characteristics

Characteristic	eQUEST Unit	Database Storage Unit	Information Source						
			LS-C	LS-D	BEPS	BEPU	PS-E	ES-D	User-Input
Annual Peak Heating Load	KBtu/hr	kW	*						
Annual Peak Cooling Load (Sensible)			*						
Annual Peak Electricity Load	kW						*		
Annual Peak Natural Gas Load	MBtu/hr						*		
Annual Building Heating Design Energy Consumption	MBtu	ekWh		*					
Annual Building Cooling Design Energy Consumption				*					
Total Annual Site Energy Usage	MBtu	ekWh			*				
Annual Site Energy Use Intensity – Gross-Area	KBtu/ft^2-yr	ekWh/m^2-yr			*				
Annual Lighting Energy Usage[a]	MBtu	ekWh			*				
Annual Miscellaneous Equipment Energy Usage					*				
Annual Space Heating Energy Usage					*				
Annual Space Cooling Energy Usage					*				
Annual Pumps, Fans and Auxiliary Energy Usage[b]					*				
Annual Domestic Hot Water Energy Usage					*				
Total Annual Electricity Usage	kWh	kWh				*			
Total Annual Natural Gas Usage	Therm	m^3				*			
Annual Renewable Electricity Generation	kWh	kWh							*
Annual Net Energy Use Intensity[c]	KBtu/ft^2-yr	ekWh/m^2-yr			*				*
Total Annual Energy Charge	$	$						*	
Annual Electricity Charge	$	$						*	
Electricity Virtual Rate	$/kWh	$/kWh						*	
Annual Natural Gas Charge	$	$						*	
Natural Gas Virtual Rate	$/Therm	$/m^3						*	

8.1.3 Dynamic Performance

A report of the hourly simulation results for a building can be generated by eQUEST for a number of variables. This dynamic performance data is collected for its potential use in urban energy planning; the information will not be used in the comparative analysis function of the online tool.

Five variables have been identified for collection: building total electricity consumption, building total natural gas consumption, building space heating electricity consumption, building space heating natural gas consumption, and building space cooling electricity consumption. The collection of these variables will provide a detailed understanding of the energy needs of the building. This can be used to facilitate planning and demand-side management by the utilities, and identify potential times of peak demand in a community (TOcore Energy Working Group 2016). Further, urban energy planners can use the hourly space heating and cooling data to coordinate micro-grid and district energy systems by finding synergies among the hourly demands of neighbouring buildings (2030 Districts 2016).

To enable the collection of hourly data, inputs must be inserted into the eQUEST input (.inp) file, prior to running the simulation. These inputs are listed in full in Appendix A; the inputs for building total electricity consumption and building total natural gas consumption have been previously defined for the TGS and HPNC program screenings, and have already been inserted into the proposed building input file.

8.2 Comparative Analysis

This section describes the comparative analysis function of the online tool. As discussed in Section 2.2, this study will use benchmarking to compare the characteristics of a proposed building against its peers. The primary goal of this analysis is to provide design guidance by drawing a correlation between these characteristics and the estimated building energy performance among similar buildings in Toronto.

An additional potential outcome of the comparative analysis is the identification of possible modelling mistakes. For instance, a characteristic that compares poorly to its peers when designed to be high-performing may have been input incorrectly in eQUEST. Even if there is no incorrect simulation, the identification of characteristics that are outliers compared to the database average may prompt the building designer to re-examine aspects of the detailed building design.

Building characteristics and performance results are collected into the database regardless of the project's level of completion, but data is marked with project stage upon collection and is stored separately if it is a completed building rather than a building in the design development phase. This distinction is made to facilitate additional levels of comparison within the database of new buildings. A building that has been entered into the database in design development stage can be compared to its own former results once it reaches project completion. The tool user can also opt to compare their design development-stage building to other buildings of a similar level of completion, or the database can be filtered to consider completed buildings, which represent the characteristics of actual new building stock in Toronto, rather than characteristics from the design development stage that may not be present in the final building.

The user is offered the opportunity to select the comparison parameters for their analysis. These comparison parameters can be any of the characteristics or metrics that were identified in Table 20, 21, or 22. The comparative analysis can be of an individual metric, or characteristics can be selected in pairs to explore the correlation between two factors. The database can be filtered by building activity type, gross floor area (facilitated as a selection from a set of defined ranges), number of floors, and/or project stage; this allows the user to compare their proposed building to the characteristics and performance of similar and/or normalized buildings.

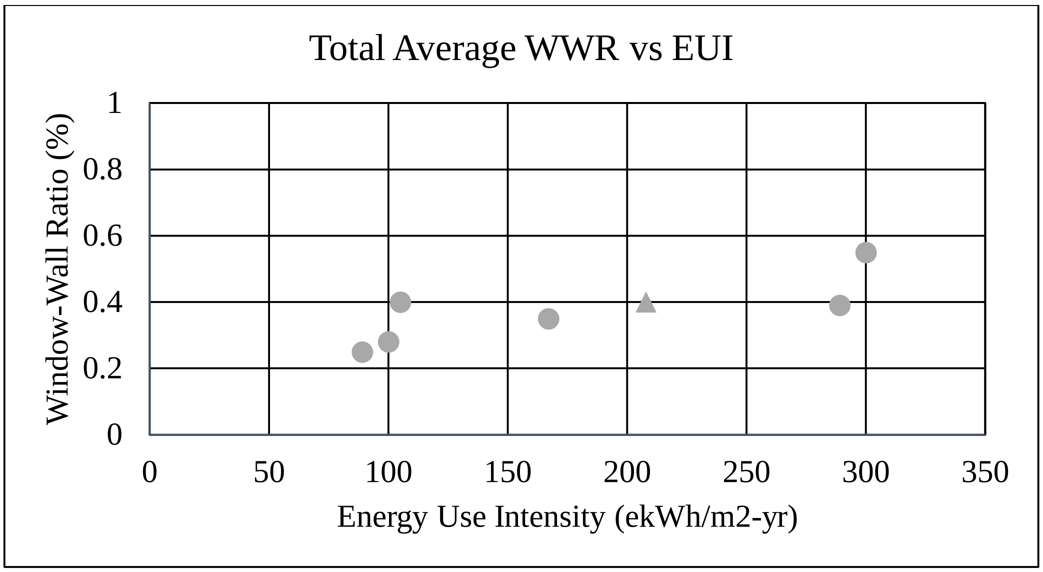
The detailed implementation of this comparative analysis will largely be determined by the database scheme developed (by others), and is summarized below.

1. The user selects their desired filter(s) and comparison metrics, as described above. These selections are stored.
2. Create a temporary comparative analysis file. Copy all database entries and input into the temporary file.
3. Apply any information filter(s) selected by the user.
4. Extract design and performance characteristics, detailed in Section 8.1, from the proposed building, and ASHRAE and OBC baseline buildings, and store in the temporary file.
5. Identify each analysis characteristic or pair of characteristics, as selected by the user, in the temporary file and display in a scatter-plot format. The proposed and baseline data should be recognisable among the database values. When an individual analysis characteristic is selected, the data should first be ranked from lowest value to highest

value for that characteristic, and displayed using the analysis characteristic value as the y-axis and rank as the x-axis.

Figure 4 is a sample comparative analysis graph comparing the window-wall ratio to the energy use intensity of all buildings. The proposed building is identified on this figure using a triangle to differentiate it from the database entries. This data is fictional, and intended to represent the conceptual design of the comparative analysis function.

Figure 4 – Sample Comparative Analysis Graph



9.0 Conclusion

In this study, a methodology has been developed for use in screening and benchmarking new buildings in Toronto using eQUEST energy simulation software. The processes, algorithms, and eQUEST inputs detailed in this report and appendices will inform the creation of a database of the estimated energy performance of new buildings in Toronto through the development of an online tool.

The detailed requirements of two reference standards are discussed, and an algorithm for automating the generation of a baseline building of comparison from the building energy model of a proposed building is presented for each standard. These baseline buildings are used along with the energy performance requirements and calculation methods of four building programs in Toronto to develop a screening process to evaluate a proposed building against the program requirements. Finally, building design and performance characteristics have been selected for inclusion in a database of new buildings in Toronto and a methodology is discussed for providing design guidance through comparative analysis.

Similarities have been identified among the program requirements that enable a streamlined screening process. For instance, the same eQUEST inputs are required to perform both TGS and HPNC program screenings, and many of the eQUEST outputs used to assess the building performance are repeated among all four programs, albeit with some program-specific additions. Further, the same OBC baseline building of reference is used for TGS and HPNC screenings. These discovered similarities demonstrate the value in performing this screening process for many programs simultaneously, and suggests that additional programs could be added to the process with limited effort. In particular, programs that use the requirements of ASHRAE 90.1 or the OBC as a baseline building will fit well into the methodology, since the generation of the baseline building files is the most complex and computationally demanding component of the overall algorithm.

The algorithms in this study are forward-thinking in their approach to program and reference standard requirements in an attempt to maintain the relevance of the program screening. Nevertheless, over time it can be anticipated that these requirements will be updated and changed to match changes in industry best practices. The methodology used to develop the screening process can be followed to develop new eQUEST inputs and screening algorithms as required. The information collected into the database should not need to be updated in this same manner.

As mentioned in Section 4.0, the relevance of an online tool based on the methodology presented in this study could be expanded through collaboration with program administration, so that the tool outputs could be directly used in the submission documentation of each program. Further, partnership with the Toronto building authorities would also be beneficial, since imposing a requirement that all new buildings use the online tool will facilitate the rapid development of the database of new buildings in Toronto.

Automating the generation of baseline HVAC systems presents the greatest potential barrier to the success of the future online tool. The algorithm developed by this investigation outlines the eQUEST commands and keywords that are needed to define each of the ten possible baseline HVAC systems. There is potential for additional commands and keywords that exist in the proposed HVAC system to remain unchanged, creating hybrid HVAC systems that do not perform as required for the baseline systems. This potential adds uncertainty and a possible source of error in the generated baselines. Further testing of the algorithm using case studies, as discussed in Section 10.2, could limit this challenge.

Overall, this study has achieved its research objective and answered the research questions that were outlined in Section 1.0. The underlying methodology for screening and benchmarking of a proposed building using an uploaded building energy model has been developed. The information required for performing the program screening has been identified, and algorithms were developed to automate the extraction of the information from the BEM. This includes extracting the information needed to automatically generate baseline building energy models for two reference standards, ASHRAE Standard 90.1-2010 and Ontario Building Code 2012. Finally, building characteristics and performance metrics have been identified based on their value in a database of simulated building energy performance of new buildings, and a methodology has been developed to facilitate design guidance through comparative analysis. The benefit of this database to utilities and urban energy planners has also been identified.

10.0 Further Work

The results of this research project lay the foundations for further related research and expanded tool functionality.

10.1 Additional Research Opportunities

1. A number of simplifications had to be made to limit the scope of this work. First, additional door and fenestration assemblies, purchased heat and/or chilled water, and commercial buildings that fall under Part 9 of the OBC were omitted from consideration. There were also simplifications made to the baseline HVAC systems. Further research is needed to incorporate these elements and bring the tool to full functionality.
2. Only eQUEST is used as the simulation software through the DOE-2.3 engine in this preliminary investigation. The methodology used to develop eQUEST inputs could be applied to other whole building energy modelling software package, such as IES and EnergyPlus, to expand the reach of the online tool.
3. Additional programs can be considered for inclusion in the screening process, e.g. Green Globes, the Living Building Challenge, and Enbridge's Savings by Design program.
4. A method for building owners to update their building data with actual metered data once the building is operational would enhance the long-term value of this tool. For instance, another prerequisite of LEED v4 BD+C is the installation of building-level energy sub-meters to provide data on the end-use energy consumption of the building and the sharing of this data with USGBC. This combined data would enable the database to evaluate the performance gap and correlate actual performance with the collected passive building system characteristics.

10.2 Tool Development

This report outlined the structure of the proposed online tool, and details the algorithms and calculations that could be implemented. These details were developed using example simulation files and hypothetical situations. To develop and test them, the decision-making process and inputs should be tested on a completed eQUEST proposed model to identify any potential errors or warnings in the input files and any gaps in the proposed approach. If possible, performing this test on eQUEST proposed models with existing baseline models would improve the quality assurance check. Deficiencies identified should be corrected at this stage to avoid complications in the software development. Once quality testing is complete, the final software interface can be developed and deployed as the online tool.

Appendices

Appendix A – Calculations and eQUEST Inputs for Baseline Creation, Program Screening, and Database Creation

(Electronic file available through Ryerson Library link)

Appendix B – ASHRAE Baseline Decision-making Process

This document outlines the eQUEST inputs and input substitutions needed to generate an ASHRAE Baseline building from an uploaded eQUEST input file. The algorithm is written in illustrative pseudo-code to show the decision-making process, intended to facilitate software development. Full software code development is outside of the scope of this project.

Contents

Key: Bolded references ("**Table X**") refer to Appendix A – Calculations and eQUEST Inputs for Baseline Creation, Program Screening, and Database Creation
eQUEST inputs are referenced using their Keyword and/or Command in CAPS
Tool inputs are defined using quotation marks
Explanatory comments and references to ASHRAE 90.1 requirements are marked with // and written in dark grey
Some system types and functions have not been implemented in the latest version of DOE-2, yet it is anticipated that they will be added in the future. These are denoted using † for systems and ‡ for functions. Refer to Report Section 6 for more detail.

Initial Set-up

User uploads eQUEST input file (.inp) for proposed building ("Proposed.inp")

User selects "Building Type", "Project Stage", "Heating Fuel", and "Cooling"

IF "Project Stage" = Completed Building, User inputs "Postal Code", and "Year of Completion"

User inputs "# Floors", "Renewable Electricity Generation – On-site", "Renewable Electricity Generation – Off-site", and "Sale Price of On-site Energy Generation"

Save new version as "Baseline.inp"

Envelope

Window-Wall Ratio and Skylight-Roof Ratio

Run eQUEST simulation for "Baseline.inp"

Open Report LV-D Details of Exterior Surfaces in "Baseline.sim" *//calculate WWR of proposed*

For ALL WALLS

"Total.WWR" = WINDOW AREA x 100 / WINDOW+WALL AREA

For ROOF

"Skylight.Ratio" = WINDOW AREA x 100 / WINDOW+WALL AREA

//reduce window area to maximum 40% WWR

IF "Total.WWR" > 40

Set "WWR.Fraction" = 40 / "Total.WWR"

For each Surface where AZIMUTH != ROOF or UNDERGRND, add to "Wall.Surface" list

Open Report LV-C Details of Space

For each Surface in "Wall.Surface" list

Select all WINDOWS and add window U-NAME to "Wall.Window" list

Close Report LV-C Details of Space

Open "Baseline.inp"

For each WINDOW where U-NAME is in "Wall.Window" list

$$WIDTH_{Reduced} = \text{"WWR.Fraction"} \times WIDTH$$

WIDTH = $WIDTH_{Reduced}$

//reduce skylight area to maximum 5% of roof

IF "Skylight.Ratio" > 5

Set "Skylight.Fraction" = 5 / "Skylight.Ratio"

For each Surface where AZIMUTH = ROOF, add to "Roof.Surface" list

Open Report LV-C Details of Space

For each Surface in "Roof.Surface" list

Select all WINDOWS and add window U-NAME to "Roof.Window" list

Close Report LV-C Details of Space

Open "Baseline.inp"

For each WINDOW where U-NAME is in "Roof.Window" list

$$WIDTH_{Reduced} = \text{"Skylight.Fraction"} \times WIDTH$$

WIDTH = $WIDTH_{Reduced}$

Close Report LV-D Details of Exterior Surfaces

Infiltration

For each SPACE in "Baseline.inp" *//sets air infiltration to 0.2 L/s-m²*

Set INF-METHOD = AIR-CHANGE

Remove input AIR-CHANGES/HR
Set INF-FLOW/AREA = 0.0124

Opaque Assemblies

Review all FLOORs in "Baseline.inp" *//calculates the R-effective of exposed underground surface*

IF any Z < 0, insert label in the FLOOR where Z is closest to Z = 0 (while still Z < 0) as "$ perim-exposed" *//means the exposed underground surface is a wall*

ELSE insert label in the FLOOR where Z = 0 as "$ slab-perim-exposed" *//means exposed underground surface is the slab-on-grade*

Calculate area of FLOOR labelled "$ perim-exposed" or "$ slab-perim-exposed", using POLYGON

Calculate the perimeter of FLOOR labelled "$ perim-exposed" or "$ slab-perim-exposed"

IF label = "$ perim-exposed" *//calculates the underground wall R-effective value*

Insert FLOOR Area and FLOOR Perimeter in **Envelope Calculations: Underground Surfaces Calculations Table** under **"$ perim-exposed" heading**

Insert all "R-fictitious" values in **Envelope -Opaque** under **"BG Wall Rfic – Exposed: RESISTANCE" heading**

ELSE *//calculates the slab R-effective value*

Insert FLOOR Area and FLOOR Perimeter in **Envelope Calculations: Underground Surfaces Calculations Table** under **"$ slab-perim-exposed" heading**

Insert all "R-fictitious" values in **Envelope -Opaque** under **"Slab Rfic – Exposed: RESISTANCE" heading**

Find "Building Type" in **Envelope Calculations: Building Type Table** *//inserts the envelope inputs based on building type*

IF "**Baseline" heading** value = Nonresidential, insert all inputs under "**Nonresidential" heading** in **Envelope -Opaque: ASHRAE 90.1-2010 Table**

Define string *XXX* = "Nonres"

ELSE insert all inputs under "**Residential" heading** in **Envelope -Opaque: ASHRAE 90.1-2010 Table**

Define string *XXX* = "Res"

Insert all inputs under **"Semiheated" heading** in **Envelope -Opaque: ASHRAE 90.1-2010 Table**

Review all ZONEs *//identifies semiheated spaces*

IF DESIGN-HEAT-T < 59, search for corresponding SPACE, and insert label "$ Semiheated"

Review all EXTERIOR-WALL

IF LOCATION = TOP *//replaces roof construction with baseline construction*

IF SPACE is labelled "$ Semiheated", set CONSTRUCTION = "ASHRAE-Roof-Semiheat"

ELSE set CONSTRUCTION = "ASHRAE-Roof-*XXX*" (using "XXX" definition above)

IF LOCATION = BOTTOM *//replaces exterior floor construction with baseline construction*

IF SPACE is labelled "$ Semiheated", set CONSTRUCTION = "ASHRAE-Floor-Semiheat"

ELSE set CONSTRUCTION = "ASHRAE-Floor-*XXX*"

ELSE *//replaces exterior wall construction with baseline construction*

IF SPACE is labelled "$ Semiheated", set CONSTRUCTION = "ASHRAE-Walls-Semiheat"

ELSE set CONSTRUCTION = "ASHRAE-Walls-*XXX*"

Review all UNDERGROUND-WALL

IF LOCATION = BOTTOM *//replaces slab construction with baseline construction*

IF FLOOR is labelled “$ slab-perim-exposed” *//chooses between two slab baseline constructions, exposed and regular*

IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “ASHRAE-Slab-Semiheat-Exp”

ELSE set CONSTRUCTION = “ASHRAE-Slab-*XXX*-Exp”

ELSE IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “ASHRAE-Slab-Semiheat”

ELSE set CONSTRUCTION = “ASHRAE-Slab-*XXX*”

ELSE IF FLOOR is labelled “$ perim-exposed” *//replaces underground wall construction with baseline construction, after choosing between two underground wall constructions, exposed and regular*

IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “ASHRAE-BGWalls-Semiheat-Exp”

ELSE set CONSTRUCTION = “ASHRAE-BGWalls-*XXX*-Exp”

ELSE IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “ASHRAE-BGWalls-Semiheat”

ELSE set CONSTRUCTION = “ASHRAE-BGWalls-*XXX*”

Review all DOOR *//replaces door construction with baseline construction*

IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “ASHRAE-Door-Semiheat”

ELSE set CONSTRUCTION = “ASHRAE-Door-*XXX*”

Fenestration

Find “Building Type” in **Envelope Calculations: Building Type Table** *//inserts fenestration inputs based on building type*

IF “**Baseline” heading** value = Nonresidential, insert all inputs under “**Nonresidential” heading** in **Envelope -Fenestration: ASHRAE 90.1-2010 Table**

Define string *XXX* = “Nonres”

ELSE insert all inputs under “**Residential” heading** in **Envelope -Fenestration: ASHRAE 90.1-2010 Table**

Define string *XXX* = “Res”

Insert all inputs under **“Semiheated” heading** in **Envelope -Fenestration: ASHRAE 90.1-2010 Table**

Review all WINDOW

IF EXTERIOR-WALL: LOCATION = TOP *//replaces skylight glass-type with baseline glass-type, based on skylight-roof ratio*

IF “Skylight %” (calculated earlier) <= 2.0

IF SPACE is labelled “$ Semiheated”, set GLASS-TYPE = “ASHRAE-Skylight-Semiheat-0-2”

ELSE set GLASS-TYPE = “ASHRAE-Skylight-*XXX-0-2*”

ELSE IF SPACE is labelled “$ Semiheated”, set GLASS-TYPE = “ASHRAE-Skylight-Semiheat-2-5”

ELSE set GLASS-TYPE = “ASHRAE-Skylight-*XXX-2-5*”

ELSE IF SPACE is labelled “$ Semiheated”, set GLASS-TYPE = “ASHRAE-Window-Semiheat” *//replaces window glass-type with baseline glass-type*

ELSE set GLASS-TYPE = “ASHRAE-Window-*XXX*”

Lighting

Review all SPACEs in “Baseline.inp”
IF LIGHTING-W/AREA is equal for all spaces *//indicates building-type method is used, replaces LPD with baseline LPD*
Find “Building Type” in **LPD-Building Type: Lighting Power Density Table**
Set LIGHTING-W/AREA = **“LPD (W/ft2)” value** for all SPACES
ELSE review each SPACE
IF C-ACTIVITY-DESC = undefined *//assigns baseline LPD using building-type method within space-by-space method, for unassigned space activity*
Find “Building Type” in **LPD-Building Type: Lighting Power Density Table**
Set LIGHTING-W/AREA = **“LPD (W/ft2)” value**
ELSE find C-ACTIVITY-DESC in **LPD-Space by Space: Lighting Power Density Table** under **“eQuest Activity Area Type”** *//uses space-by-space method, replaces LPD with baseline LPD*
Set LIGHTING-W/AREA = **“LPD (W/ft2)” value**
Review all SPACE *//sets lighting characteristics to baseline*
Set LTG-SPEC-METHOD = POWER-DEFINITION
Set LIGHTING-TYPE = SUS-FLUOR
Set TASK-LT-W/AREA = 0
Set DAYLIGHTING = NO
Remove inputs: NO-OF-LUMINARIES, LIGHTING-SYSTEM, LUM-SPACE-DIV, CEIL-TO-LUM-DIS, WORKPLANE-HEIGHT, ELEC-ILLUMINANCE

HVAC
Review DESIGN-DAY : TYPE = COOLING *//requirement G3.1.2.2.1*
Set DRYBULB-HIGH = 84
Set DRYBULB-RANGE = 20
Set WETBULB-AT-HIGH = 70
Review DESIGN-DAY : TYPE = HEATING *//req. G3.1.2.2.1*
Set DRYBULB-HIGH = -4
Run “Baseline.inp” simulation

Review <u>Report LS-C Building Peak Load Components</u> in “Baseline.sim”
Extract FLOOR-AREA in SQFT (“Building Area”)
Find “Building Type” in **HVAC System: Building Type Table** *//determine the baseline HVAC system type based on Table G3.1.1A*
IF **“Baseline” Value** = “Residential”
IF “Heating Fuel” = “Electric”, follow “†System 2 Process”, on page B-9
ELSE follow “†System 1 Process”, below on page B-6
ELSE IF **“Baseline” Value** = “Storage” AND “Cooling” = NO
IF “Heating Fuel” = “Electric”, follow “†System 10 Process” on page B-35
ELSE follow “†System 9 Process” on page B-33
ELSE IF “# Floors” <= 3 AND “Building Area” < 24,541
IF “Heating Fuel” = “Electric”, follow “System 4 Process” on page B-13
ELSE follow “System 3 Process” on page B-11
ELSE IF “# Floors” <= 5 AND > 3 AND “Building Area” < 24,541
IF “Heating Fuel” = “Electric”, follow “System 6 Process” on page B-19
ELSE follow “System 5 Process” on page B-15

ELSE IF "# Floors" <= 5 AND "Building Area" <= 149,380 AND > 24,541
IF "Heating Fuel" = "Electric", follow "System 6 Process" on page B-19
ELSE follow "System 5 Process" on page B-15
ELSE IF "# Floors" > 5
IF "Heating Fuel" = "Electric", follow "System 8 Process" on page B-28
ELSE follow "System 7 Process" on page B-22
ELSE (for "Building Area" > 149,380)
IF "Heating Fuel" = "Electric", follow "System 8 Process" on page B-28
ELSE follow "System 7 Process" on page B-22

†System 1 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components ("Peak Cooling") *//used for selecting cooling equipment efficiency*
Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components ("Peak Heating") *//used for selecting heating equipment efficiency*
Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*
Review all CIRCULATION-LOOP *//removes unused inputs, leaves DHW*
IF TYPE =/ DHW, remove all inputs

Insert Pump Power Curve under Performance Curves:
Set "Baseline HW Pump Power" = CURVE-FIT *//for req. G3.1.3.5*
Set TYPE = LINEAR
Set INPUT-TYPE = DATA
Set INDEPENDENT = (1, 2)
Set DEPENDENT = (19, 38)
Insert Boiler Pump under Pumps:
Set "Baseline Boiler Pump" = PUMP
IF "Building Area" > 120125, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.5*
ELSE set CAP-CTRL = ONE-SPEED-PUMP
Set PUMP-HP-FLOW = "Baseline HW Pump Power" *//req. G3.1.3.5*
Insert Boiler Loop under Circulation Loops:
Set "Baseline Boiler Loop" = CIRCULATION-LOOP
Set TYPE = HW
Set LOOP-OPERATION = STANDBY
Set LOOP-DESIGN-DT = 50.4 *//req. G3.1.3.3*
Set HEAT-SETPT-CTRL = OA-RESET *//req. G3.1.3.4*
Set HEAT-SETPT-SCH = "Baseline Boiler Reset"
Set LOOP-PUMP = "Baseline Boiler Pump"
Insert Boiler under Boilers:
Set "Baseline Boiler 1" = BOILER
Set TYPE = HW-BOILER
IF "Peak Heating" < 733 kW, set HEAT-INPUT-RATIO = 1.25 *//req. G3.1.2.1*
ELSE set HEAT-INPUT-RATIO = 1.22
Set HW-LOOP = "Baseline Boiler Loop"
Set AQUASTAT-SETPT-T = 180 *//req. G3.1.3.3*

IF “Building Area” >15,069 *//req. G3.1.3.2*
Set “Baseline Boiler 2” = BOILER
Set TYPE = HW-BOILER
IF “Peak Heating” < 733, set HEAT-INPUT-RATIO = 1.25 *//req. G3.1.2.1*
ELSE set HEAT-INPUT-RATIO = 1.22
Set HW-LOOP = “Baseline Boiler Loop”
Set AQUASTAT-SETPT-T = 180 *//req. G3.1.3.3*
Insert Boiler Reset Schedules:
Set “Day Baseline Boiler Reset” = DAY-SCHEDULE-PD *//req. G3.1.3.4*
Set TYPE = RESET-TEMP
Set OUTSIDE-HI = 50
Set OUTSIDE-LO = 19.4
Set SUPPLY-HI = 180
Set SUPPLY-LO = 151
Set “Week Baseline Boiler Reset” = WEEK-SCHEDULE-PD
Set TYPE = RESET-TEMP
Set DAY-SCHEDULES = (“Day Baseline Boiler Reset”, &D, &D, &D, &D, “Day Baseline Boiler Reset”)
Set “Baseline Boiler Reset” = SCHEDULE-PD
Set TYPE = RESET TEMP
Set MONTH = (12)
Set DAY = (31)
Set WEEK-SCHEDULES = (“Week Baseline Boiler Reset”)

Review all SYSTEM
† Set TYPE = PTAC *//per Table G3.1.1B*
Calculate COOLING-EIR *//req. G3.1.2.1*
COOLING-EIR = 1 / [(4.04 – (0.300 x “Peak Cooling” / 1000) x 3.412]
Set COOL-EIR-FT = DX-Cool-EIR-fEWB&OAT *//per Table G3.1.1B*
Set COOL-EIR-FPLR = DX-Cool-EIR-fPLR
Set COOL-SIZING-RATI = 1.15 *//req. G3.1.2.2*
Set HEAT-SOURCE = HOT-WATER *//per Table G3.1.1B*
Set ZONE-HEAT-SOURCE = NONE
Set BASEBOARD-SOURCE = NONE
Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*
Set HEAT-CONTROL = CONSTANT
Set HW-LOOP = “Baseline Boiler Loop”
Set OA-CONTROL = FIXED *//req. G3.1.2.7*
Set MAX-OA-FRACTION = 1.0
Set FAN-CONTROL = CONSTANT-VOLUME *//per Table G3.1.1B*

Review all ZONE where TYPE = CONDITIONED
For corresponding SPACE
Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **“eQuest Activity Area Type”**
Extract **“CFM/Person” value** and **“CFM/ft2” value** *//determine ASHRAE 62.1 requirements*

Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*

Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*

IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*

IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*

IF NUMBER-OF-PEOPLE =/ "undefined"

Calculate design outdoor air flow ("Design OA")

"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x NUMBER-OF-PEOPLE

Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")

*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x NUMBER-OF-PEOPLE*

ELSE

Calculate Occupancy ("Occupancy")

"Occupancy" = 1 / (AREA/PERSON) x "Space Area"

Calculate design outdoor air flow ("Design OA")

"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x "Occupancy"

Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")

*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x "Occupancy"*

Calculate "Air Flow Rate" *//req. G3.1.2.9.1*

*"Air Flow Rate" = [("Space Cooling" / (1.02 kg/m^3 x 1.2 kJ/kg x 11.1K))*1.15] * 2,118.8*

IF "Air Flow Rate" > "ASHRAE OA", set FLOW/AREA = ("Air Flow Rate" / "Space Area")

ELSE set FLOW/AREA = ("ASHRAE OA" / "Space Area")

Calculate design air flow ("Design Flow")

*"Design Flow" = FLOW/AREA * "Space Area"*

Review all SYSTEM

Set SUPPLY-KW/FLOW = 0.64 *//req. G3.1.2.10*

Remove SUPPLY-STATIC input

‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA ("% OA")

"% OA" = Sum "Design OA" / Sum SUPPLY-FLOW

IF "% OA" < 0.3, set RECOVER-EXHAUST = NO

ELSE Find "% OA" on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **">=" and "<" values**

IF SUPPLY-FLOW >= **"Design Supply Airflow Rate" value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at "*Service Hot Water*" on page B-37

†System 2 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components ("Peak Cooling") *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components ("Peak Heating") *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP *//removes unused inputs, leaves DHW*

IF TYPE =/ DHW, remove all inputs

Review all SYSTEM

† Set TYPE = PTAC *//per Table G3.1.1B*

Calculate COOLING-EIR *//req. G3.1.2.1*

COOLING-EIR = 1 / ([4.10 – (0.300 x "Peak Cooling" / 1000)] x 3.412)

Set COOL-EIR-FT = DX-Cool-EIR-fEWB&OAT *//per Table G3.1.1B*

Set COOL-EIR-FPLR = DX-Cool-EIR-fPLR

Set COOL-SIZING-RATI = 1.15 *//req. G3.1.2.2*

Set HEAT-SOURCE = HEAT-PUMP *//per Table G3.1.1B*

Set ZONE-HEAT-SOURCE = NONE

Set BASEBOARD-SOURCE = NONE

Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*

Calculate HEATING-EIR *//req. G3.1.2.1*

HEATING-EIR = 1 / (3.7 – (0.052 x "Peak Heating" / 1000))

Set HP-SUPP-SOURCE = ELECTRIC

Set HEAT-EIR-FT = PVVT-Heat-EIR-fEDB&OAT

Set HEAT-EIR-FPLR = PVVT-Heat-EIR-fPLR

Set MAX-HP-SUPP-T = 39 *//req. G3.1.3.1*

Set OA-CONTROL = FIXED *//req. G3.1.2.7*

Set MAX-OA-FRACTION = 1.0

Set FAN-CONTROL = CONSTANT-VOLUME *//per Table G3.1.1B*

Review all ZONE where TYPE = CONDITIONED

For corresponding SPACE

Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**

Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*

Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*

Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*

IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*

IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*

IF NUMBER-OF-PEOPLE =/ "undefined"

Calculate design outdoor air flow (“Design OA”)

“Design OA” = OA-FLOW/AREA x “Space Area” + OA-FLOW/PER x NUMBER-OF-PEOPLE

Calculate ASHRAE minimum outdoor air requirement (“ASHRAE OA”)

*“ASHRAE OA” = **“CFM/ft2”** x “Space Area” + **“CFM/Person”** x NUMBER-OF-PEOPLE*

ELSE

Calculate Occupancy (“Occupancy”)

“Occupancy” = 1 / (AREA/PERSON) x “Space Area”

Calculate design outdoor air flow (“Design OA”)

“Design OA” = OA-FLOW/AREA x “Space Area” + OA-FLOW/PER x “Occupancy”

Calculate ASHRAE minimum outdoor air requirement (“ASHRAE OA”)

*“ASHRAE OA” = **“CFM/ft2”** x “Space Area” + **“CFM/Person”** x “Occupancy”*

Calculate “Air Flow Rate” *//req. G3.1.2.9.1*

*“Air Flow Rate” = [(“Space Cooling” / (1.02 kg/m^3 x 1.2 kJ/kg x 11.1K))*1.15] * 2,118.8*

IF “Air Flow Rate” > “ASHRAE OA”, set FLOW/AREA = (“Air Flow Rate” / “Space Area”)

ELSE set FLOW/AREA = (“ASHRAE OA” / “Space Area”)

Calculate design air flow (“Design Flow”)

*“Design Flow” = FLOW/AREA * “Space Area”*

Review all SYSTEM

Set SUPPLY-KW/FLOW = 0.64 *//req. G3.1.2.10*

Remove SUPPLY-STATIC input

‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA (“% OA”)

“% OA” = Sum “Design OA” / Sum SUPPLY-FLOW

IF “% OA” < 0.3, set RECOVER-EXHAUST = NO

ELSE Find “% OA” on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **“>=” and “<” values**

IF SUPPLY-FLOW >= **“Design Supply Airflow Rate” value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at “*Service Hot Water*” on page B-37

System 3 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components ("Peak Cooling") *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components ("Peak Heating") *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP *//removes unused inputs, leaves DHW*

IF TYPE =/ DHW, remove all inputs

Review all SYSTEM

Set TYPE = PSZ *//per Table G3.1.1B*

IF "Peak Cooling" < 19 kW, set COOLING-EIR = 0.2122 *//req. G3.1.2.1*

ELSE IF "Peak Cooling" >= 19 kW AND < 40 kW, set COOLING-EIR = 0.2529

ELSE IF "Peak Cooling" >= 40 kW AND < 70 kW, set COOLING-EIR = 0.2584

ELSE IF "Peak Cooling" >= 70 kW AND < 223 kW, set COOLING-EIR = 0.2879

ELSE set COOLING-EIR = 0.2983

Set COOL-EIR-FT = DX-Cool-EIR-fEWB&OAT *//per Table G3.1.1B*

Set COOL-EIR-FPLR = DX-Cool-EIR-fPLR

Set COOL-SIZING-RATI = 1.15 *//req. G3.1.2.2*

Set HEAT-SOURCE = FURNACE *//per Table G3.1.1B*

Set ZONE-HEAT-SOURCE = NONE

Set BASEBOARD-SOURCE = NONE

Set FURNACE-HIR = 1.25 *//req. G3.1.2.1*

Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*

Set FURNACE-HIR-FPLR = Furnace-HIR-fPLR

Set OA-CONTROL = OA-TEMP *//req. G3.1.2.7*

Set ECONO-LIMIT-T = 70 *//req. G3.1.2.8*

Set MAX-OA-FRACTION = 1.0

Set FAN-CONTROL = CONSTANT-VOLUME *//per Table G3.1.1B*

Review all ZONE where TYPE = CONDITIONED

For corresponding SPACE

Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**

Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*

Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*

Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*

IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*

IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*

IF NUMBER-OF-PEOPLE =/ "undefined"

Calculate design outdoor air flow ("Design OA")

“Design OA” = OA-FLOW/AREA x “Space Area” + OA-FLOW/PER x NUMBER-OF-PEOPLE

Calculate ASHRAE minimum outdoor air requirement (“ASHRAE OA”)

“ASHRAE OA” = ***“CFM/ft2”*** *x “Space Area” +* ***“CFM/Person”*** *x NUMBER-OF-PEOPLE*

ELSE

Calculate Occupancy (“Occupancy”)

“Occupancy” = 1 / (AREA/PERSON) x “Space Area”

Calculate design outdoor air flow (“Design OA”)

“Design OA” = OA-FLOW/AREA x “Space Area” + OA-FLOW/PER x “Occupancy”

Calculate ASHRAE minimum outdoor air requirement (“ASHRAE OA”)

“ASHRAE OA” = ***“CFM/ft2”*** *x “Space Area” +* ***“CFM/Person”*** *x “Occupancy”*

Calculate “Air Flow Rate” *//req. G3.1.2.9.1*

*“Air Flow Rate” = [(“Space Cooling” / (1.02 kg/m^3 x 1.2 kJ/kg x 11.1 K))*1.15] * 2,118.8*

IF “Air Flow Rate” > “ASHRAE OA”, set FLOW/AREA = (“Air Flow Rate” / “Space Area”)

ELSE set FLOW/AREA = (“ASHRAE OA” / “Space Area”)

Calculate design air flow (“Design Flow”)

*“Design Flow” = FLOW/AREA * “Space Area”*

Review all SYSTEM

IF RETURN-FLOW =/ “undefined” *//req. G3.1.2.9.1*

Review corresponding ZONEs

IF (“Design Flow” – “ASHRAE OA”) > (“Design Flow” x 0.9), set RETURN-FLOW = (“Design Flow” – “ASHRAE OA”)

ELSE set RETURN-FLOW = (“Design Flow” x 0.9)

For corresponding ZONEs

Sum “Design Flow”, convert to metric (“Design Flow L/s”)

“Design Flow L/s” = SUPPLY-FLOW [CFM] / 2.1188

Calculate Input kW (“Input kW”) *//req. G3.1.2.10*

*“Input kW” = “Design Flow L/s” * 0.0015 + SUPPLY-STATIC x 250*

Find **“Fan Motor Efficiency” value** of **HVAC Equipment: ASHRAE Table 10.8B** for “Input kW”, using closest “**Motor Input kW” value** > “Input kW”

Set SUPPLY-MTR-EFF = **“Fan Motor Efficiency”**

‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA (“% OA”)

“% OA” = Sum “Design OA” / Sum SUPPLY-FLOW

IF “% OA” < 0.3, set RECOVER-EXHAUST = NO

ELSE Find “% OA” on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **“>=” and “<” values**

IF SUPPLY-FLOW >= **“Design Supply Airflow Rate” value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at “*Service Hot Water”* on page B-37

System 4 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components ("Peak Cooling") *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components ("Peak Heating") *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP
- IF TYPE =/ DHW, remove all inputs *//removes unused inputs, leaves DHW*

Review all SYSTEM
- Set TYPE = PSZ *//per Table G3.1.1B*
- IF "Peak Cooling" < 19 kW, set COOLING-EIR = 0.2122 *//req. G3.1.2.1*
- ELSE IF "Peak Cooling" >= 19 kW AND < 40 kW, set COOLING-EIR = 0.2584
- ELSE IF "Peak Cooling" >= 40 kW AND < 70 kW, set COOLING-EIR = 0.2689
- ELSE set COOLING-EIR = 0.3056
- Set COOL-EIR-FT = DX-Cool-EIR-fEWB&OAT *//per Table G3.1.1B*
- Set COOL-EIR-FPLR = DX-Cool-EIR-fPLR
- Set COOL-SIZING-RATI = 1.15 *//req. G3.1.2.2*
- Set HEAT-SOURCE = HEAT-PUMP *//per Table G3.1.1B*
- Set ZONE-HEAT-SOURCE = NONE
- Set BASEBOARD-SOURCE = NONE
- IF "Peak Heating" < 19 kW, set HEATING-EIR = 0.3851 *//req. G3.1.2.1*
- ELSE IF "Peak Heating" >= 19 kW AND < 40 kW, set HEATING-EIR = 0.3870
- ELSE set HEATING-EIR = 0.4286
- Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*
- Set HEAT-EIR-FT = PVVT-Heat-EIR-fEDB&OAT
- Set HEAT-EIR-FPLR = PVVT-Heat-EIR-fPLR
- Set HP-SUPP-SOURCE = ELECTRIC *//req. G3.1.3.1*
- Set MAX-HP-SUPP-T = 39 *//req. G3.1.3.1*
- Set OA-CONTROL = OA-TEMP *//req. G3.1.2.7*
- Set ECONO-LIMIT-T = 70 *//req. G3.1.2.8*
- Set MAX-OA-FRACTION = 1.0
- Set FAN-CONTROL = CONSTANT-VOLUME *//per Table G3.1.1B*

Review all ZONE where TYPE = CONDITIONED
- For corresponding SPACE
  - Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**
  - Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*
  - Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*
  - Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*
- IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*

IF OA-FLOW/PER > **“CFM/Person” value**, set OA-FLOW/PER = **“CFM/Person” value** *//req. G3.1.2.6*

IF NUMBER-OF-PEOPLE =/ “undefined”

Calculate design outdoor air flow (“Design OA”)

“Design OA” = OA-FLOW/AREA x “Space Area” + OA-FLOW/PER x NUMBER-OF-PEOPLE

Calculate ASHRAE minimum outdoor air requirement (“ASHRAE OA”)

*“ASHRAE OA” = **“CFM/ft2”** x “Space Area” + **“CFM/Person”** x NUMBER-OF-PEOPLE*

ELSE

Calculate Occupancy (“Occupancy”)

“Occupancy” = 1 / (AREA/PERSON) x “Space Area”

Calculate design outdoor air flow (“Design OA”)

“Design OA” = OA-FLOW/AREA x “Space Area” + OA-FLOW/PER x “Occupancy”

Calculate ASHRAE minimum outdoor air requirement (“ASHRAE OA”)

*“ASHRAE OA” = **“CFM/ft2”** x “Space Area” + **“CFM/Person”** x “Occupancy”*

Calculate “Air Flow Rate” *//req. G3.1.2.9.1*

*“Air Flow Rate” = [(“Space Cooling” / (1.02 kg/m^3 x 1.2 kJ/kg x 11.1 K))*1.15] * 2,118.8*

IF “Air Flow Rate” > “ASHRAE OA”, set FLOW/AREA = (“Air Flow Rate” / “Space Area”)

ELSE set FLOW/AREA = (“ASHRAE OA” / “Space Area”)

Calculate design air flow (“Design Flow”)

*“Design Flow” = FLOW/AREA * “Space Area”*

Review all SYSTEM

IF RETURN-FLOW =/ “undefined” *//req. G3.1.2.9.1*

Review corresponding ZONEs

IF (“Design Flow” – “ASHRAE OA”) > (“Design Flow” x 0.9), set RETURN-FLOW = (“Design Flow” – “ASHRAE OA”)

ELSE set RETURN-FLOW = (“Design Flow” x 0.9)

For corresponding ZONEs

Sum “Design Flow”, convert to metric (“Design Flow L/s”)

“Design Flow L/s” = SUPPLY-FLOW [CFM] / 2.1188

Calculate Input kW (“Input kW”) *//req. G3.1.2.10*

*“Input kW” = “Design Flow L/s” * 0.0015 + SUPPLY-STATIC x 250*

Find **“Fan Motor Efficiency” value** of **HVAC Equipment: ASHRAE Table 10.8B** for “Input kW”, using closest “**Motor Input kW” value** > “Input kW”

Set SUPPLY-MTR-EFF = **“Fan Motor Efficiency”**

‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA (“% OA”)

“% OA” = Sum “Design OA” / Sum SUPPLY-FLOW

IF “% OA” < 0.3, set RECOVER-EXHAUST = NO

ELSE Find “% OA” on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **“>=” and “<” values**

IF SUPPLY-FLOW >= **“Design Supply Airflow Rate” value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at “*Service Hot Water*” on page B-37

System 5 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components (“Peak Cooling”) *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components (“Peak Heating”) *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP
IF TYPE =/ DHW, remove all inputs *//removes unused inputs, leaves DHW*

Review all SYSTEM
Set TYPE = PVAVS *//per Table G3.1.1B*
Set COOL-CONTROL = WARMEST *//for req. G3.1.3.12*
IF “Peak Cooling” < 19 kW, set COOLING-EIR = 0.2122 *//req. G3.1.2.1*
ELSE IF “Peak Cooling” >= 19 kW AND < 40 kW, set COOLING-EIR = 0.2529
ELSE IF “Peak Cooling” >= 40 kW AND < 70 kW, set COOLING-EIR = 0.2584
ELSE IF “Peak Cooling” >= 70 kW AND < 223 kW, set COOLING-EIR = 0.2879
ELSE set COOLING-EIR = 0.2983
Set COOL-EIR-FT = DX-Cool-EIR-fEQB&OAT *//per Table G3.1.1B*
Set COOL-EIR-FPLR = DX-Cool-EIR-fPLR
Set COOL-SIZING-RATI = 1.15 *//req. G3.1.2.2*
Set COOL-MAX-RESET-T = 59.1 *//req. G3.1.3.12*
Set HEAT-SOURCE = HOT-WATER *//per Table G3.1.1B*
Set ZONE-HEAT-SOURCE = HOT-WATER *//per Table G3.1.1B*
Set BASEBOARD-SOURCE = NONE
Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*
Set HEAT-CONTROL = CONSTANT
Set HW-LOOP = “Baseline Boiler Loop” *//per Table G3.1.1B*
Set OA-CONTROL = OA-TEMP *//req. G3.1.2.7*
Set ECONO-LIMIT-T = 70 *//req. G3.1.2.8*
Set MAX-OA-FRACTION = 1.0
Set FAN-CONTROL = FAN-EIR-FPLR *//req. G3.1.3.15*
Set FAN-EIR-FPLR = “Baseline Part-Load Fan Power”
Set REHEAT-DELTA-T = 18

Insert Pump Power Curve under Performance Curves:
Set “Baseline HW Pump Power” = CURVE-FIT *//for req. G3.1.3.5*
Set TYPE = LINEAR
Set INPUT-TYPE = DATA
Set INDEPENDENT = (1, 2)
Set DEPENDENT = (19, 38)

Insert Boiler Pump under Pumps:
Set “Baseline Boiler Pump” = PUMP
IF “Building Area” > 120125, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.5*
ELSE set CAP-CTRL = ONE-SPEED-PUMP
Set PUMP-HP-FLOW = “Baseline HW Pump Power” *//req. G3.1.3.5*

Insert Boiler Loop under Circulation Loops:

Set “Baseline Boiler Loop” = CIRCULATION-LOOP
Set TYPE = HW
Set LOOP-OPERATION = STANDBY
Set LOOP-DESIGN-DT = 50.4 *//req. G3.1.3.3*
Set HEAT-SETPT-CTRL = OA-RESET *//req. G3.1.3.4*
Set HEAT-SETPT-SCH = “Baseline Boiler Reset”
Set LOOP-PUMP = “Baseline Boiler Pump”
Insert Boiler under Boilers:
Set “Baseline Boiler 1” = BOILER
Set TYPE = HW-BOILER
IF “Peak Heating” < 733 kW, set HEAT-INPUT-RATIO = 1.25 *//req. G3.1.2.1*
ELSE set HEAT-INPUT-RATIO = 1.22
Set HW-LOOP = “Baseline Boiler Loop”
Set AQUASTAT-SETPT-T = 180 *//req. G3.1.3.3*
IF “Building Area” >15,069 *//req. G3.1.3.2*
Set “Baseline Boiler 2” = BOILER
Set TYPE = HW-BOILER
IF “Peak Heating” < 733, set HEAT-INPUT-RATIO = 1.25 *//req. G3.1.2.1*
ELSE set HEAT-INPUT-RATIO = 1.22
Set HW-LOOP = “Baseline Boiler Loop”
Set AQUASTAT-SETPT-T = 180 *//req. G3.1.3.3*
Insert Boiler Reset Schedules:
Set “Day Baseline Boiler Reset” = DAY-SCHEDULE-PD *//req. G3.1.3.4*
Set TYPE = RESET-TEMP
Set OUTSIDE-HI = 50
Set OUTSIDE-LO = 19.4
Set SUPPLY-HI = 180
Set SUPPLY-LO = 151
Set “Week Baseline Boiler Reset” = WEEK-SCHEDULE-PD
Set TYPE = RESET-TEMP
Set DAY-SCHEDULES = (“Day Baseline Boiler Reset”, &D, &D, &D, &D, “Day Baseline Boiler Reset”)
Set “Baseline Boiler Reset” = SCHEDULE-PD
Set TYPE = RESET TEMP
Set MONTH = (12)
Set DAY = (31)
Set WEEK-SCHEDULES = (“Week Baseline Boiler Reset”)

Insert VAV Fan Performance Curve *//req. G3.1.3.15*
Set “Baseline Part-Load Fan Power” = CURVE-FIT
Set TYPE = CUBIC
Set INPUT-TYPE = COEFFICIENTS
Set COEFFICIENTS = (0.0013, 0.147, 0.9506, 0.0998)

Review all ZONE where TYPE = CONDITIONED
Set TERMINAL-TYPE = SVAV *//per Table G3.1.1B*
For corresponding SPACE

Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**
Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*
Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*
Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*
IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*
IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*
IF NUMBER-OF-PEOPLE =/ "undefined"
Calculate design outdoor air flow ("Design OA")
"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x NUMBER-OF-PEOPLE
Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")
*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x NUMBER-OF-PEOPLE*
ELSE
Calculate Occupancy ("Occupancy")
"Occupancy" = 1 / (AREA/PERSON) x "Space Area"
Calculate design outdoor air flow ("Design OA")
"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x "Occupancy"
Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")
*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x "Occupancy"*
Calculate "Air Flow Rate" *//req. G3.1.2.9.1*
*"Air Flow Rate" = [("Space Cooling" / (1.02 kg/m^3 x 1.2 kJ/kg x 11.1 K))*1.15] * 2,118.8*
IF "Air Flow Rate" > "ASHRAE OA", set FLOW/AREA = ("Air Flow Rate" / "Space Area")
ELSE set FLOW/AREA = ("ASHRAE OA" / "Space Area")
Calculate design air flow ("Design Flow")
*"Design Flow" = FLOW/AREA * "Space Area"*
Set MIN-FLOW-RATIO = 0.3 *//req. G3.1.3.13*

Review all SYSTEM
IF RETURN-FLOW =/ "undefined" *//req. G3.1.2.9.1*
Review corresponding ZONEs
IF ("Design Flow" – "ASHRAE OA") > ("Design Flow" x 0.9), set RETURN-FLOW = ("Design Flow" – "ASHRAE OA")
ELSE set RETURN-FLOW = ("Design Flow" x 0.9)
For corresponding ZONEs
Sum "Design Flow", convert to metric ("Design Flow L/s")
"Design Flow L/s" = SUPPLY-FLOW [CFM] / 2.1188
Calculate Input kW ("Input kW") *//req. G3.1.2.10*
*"Input kW" = "Design Flow L/s" * 0.0021 + SUPPLY-STATIC x 250*
Find **"Fan Motor Efficiency" value** of **HVAC Equipment: ASHRAE Table 10.8B** for "Input kW", using closest "**Motor Input kW" value** > "Input kW"
Set SUPPLY-MTR-EFF = **"Fan Motor Efficiency"**
‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA (“% OA”)

“% OA” = Sum “Design OA” / Sum SUPPLY-FLOW

IF “% OA” < 0.3, set RECOVER-EXHAUST = NO

ELSE Find “% OA” on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **“>=” and “<” values**

IF SUPPLY-FLOW >= **“Design Supply Airflow Rate” value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at “*Service Hot Water”* on page B-37

System 6 Process

Extract TOTAL LOAD : COOLING (KW) from <u>Report LS-C Building Peak Load Components</u> (“Peak Cooling”) *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from <u>Report LS-C Building Peak Load Components</u> (“Peak Heating”) *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP

IF TYPE =/ DHW, remove all inputs *//removes unused inputs, leaves DHW*

Review all SYSTEM

Set TYPE = PIU *//removes unused inputs, leaves DHW*

Set COOL-SOURCE = ELEC-DX *//per Table G3.1.1B*

Set CONDENSER-TYPE = AIR-COOLED *//per Table G3.1.1B*

Set COOL-CONTROL = WARMEST *//for req. G3.1.3.12*

IF “Peak Cooling” < 19 kW, set COOLING-EIR = 0.2122 *//req. G3.1.2.1*

ELSE IF “Peak Cooling” >= 19 kW AND < 40 kW, set COOLING-EIR = 0.2529

ELSE IF “Peak Cooling” >= 40 kW AND < 70 kW, set COOLING-EIR = 0.2584

ELSE IF “Peak Cooling” >= 70 kW AND < 223 kW, set COOLING-EIR = 0.2879

ELSE set COOLING-EIR = 0.2983

Set COOL-EIR-FT = DX-Cool-EIR-fEQB&OAT *//per Table G3.1.1B*

Set COOL-EIR-FPLR = DX-Cool-EIR-fPLR

Set COOL-SIZING-RATI = 1.15 *//req. G3.1.2.2*

Set COOL-MAX-RESET-T = 59.1 *//req. G3.1.3.12*

Set HEAT-SOURCE = ELECTRIC *//per Table G3.1.1B*

Set ZONE-HEAT-SOURCE = ELECTRIC *//per Table G3.1.1B*

Set BASEBOARD-SOURCE = NONE

Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*

Set OA-CONTROL = OA-TEMP *//req. G3.1.2.7*

Set ECONO-LIMIT-T = 70 *//req. G3.1.2.8*

Set MAX-OA-FRACTION = 1.0

Set FAN-CONTROL = FAN-EIR-FPLR *//req. G3.1.3.15*

Set FAN-EIR-FPLR = “Baseline Part-Load Fan Power”

Set REHEAT-DELTA-T = 18

Insert VAV Fan Performance Curve *//req. G3.1.3.15*

Set “Baseline Part-Load Fan Power” = CURVE-FIT

Set TYPE = CUBIC

Set INPUT-TYPE = COEFFICIENTS

Set COEFFICIENTS = (0.0013, 0.147, 0.9506, 0.0998)

Review all ZONE where TYPE = CONDITIONED

Set TERMINAL-TYPE = PARALLEL-PIU *//per Table G3.1.1B*

Set ZONE-FAN-RUN = HEATING-ONLY

Set ZONE-FAN-CTRL = VARIABLE-VOLUME *//per Table G3.1.1B*

Set ZONE-FAN-KW/FLOW = 0.000349 *//req. G3.1.3.14*

Set ZONE-FAN-RATIO = 0.5 *//req. G3.1.3.14*

For corresponding SPACE

Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**

Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*

Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*

Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*

IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*

IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*

IF NUMBER-OF-PEOPLE =/ "undefined"

Calculate design outdoor air flow ("Design OA")

"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x NUMBER-OF-PEOPLE

Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")

*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x NUMBER-OF-PEOPLE*

ELSE

Calculate Occupancy ("Occupancy")

"Occupancy" = 1 / (AREA/PERSON) x "Space Area"

Calculate design outdoor air flow ("Design OA")

"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x "Occupancy"

Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")

*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x "Occupancy"*

Calculate "Air Flow Rate" *//req. G3.1.2.9.1*

*"Air Flow Rate" = [("Space Cooling" / (1.02 kg/m^3 x 1.2 kJ/kg x 11.1 K))*1.15] * 2,118.8*

IF "Air Flow Rate" > "ASHRAE OA", set FLOW/AREA = ("Air Flow Rate" / "Space Area")

ELSE set FLOW/AREA = ("ASHRAE OA" / "Space Area")

Calculate design air flow ("Design Flow")

*"Design Flow" = FLOW/AREA * "Space Area"*

Set MIN-FLOW-RATIO = 0.3 *//req. G3.1.3.14*

Review all SYSTEM

IF RETURN-FLOW =/ "undefined" *//req. G3.1.2.9.1*

Review corresponding ZONEs

IF ("Design Flow" – "ASHRAE OA") > ("Design Flow" x 0.9), set RETURN-FLOW = ("Design Flow" – "ASHRAE OA")

ELSE set RETURN-FLOW = ("Design Flow" x 0.9)

For corresponding ZONEs

Sum "Design Flow", convert to metric ("Design Flow L/s")

"Design Flow L/s" = SUPPLY-FLOW [CFM] / 2.1188

Calculate Input kW ("Input kW") *//req. G3.1.2.10*

*"Input kW" = "Design Flow L/s" * 0.0021 + SUPPLY-STATIC x 250*

Find **"Fan Motor Efficiency" value** of **HVAC Equipment: ASHRAE Table 10.8B** for "Input kW", using closest "**Motor Input kW" value** > "Input kW"

Set SUPPLY-MTR-EFF = **"Fan Motor Efficiency"**

‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA (“% OA”)

“% OA” = Sum “Design OA” / Sum SUPPLY-FLOW

IF “% OA” < 0.3, set RECOVER-EXHAUST = NO

ELSE Find “% OA” on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **“>=” and “<” values**

IF SUPPLY-FLOW >= **“Design Supply Airflow Rate” value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at “*Service Hot Water*” on page B-37

System 7 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components ("Peak Cooling") *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components ("Peak Heating") *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP
    IF TYPE =/ DHW, remove all inputs *//removes unused inputs, leaves DHW*

Insert Pump Power Curve under Performance Curves:
    Set "Baseline HW Pump Power" = CURVE-FIT *//for req. G3.1.3.5*
    Set TYPE = LINEAR
    Set INPUT-TYPE = DATA
    Set INDEPENDENT = (1, 2)
    Set DEPENDENT = (19, 38)
    Set "Baseline CHW Pump Power" = CURVE-FIT *//for req. G3.1.3.10*
    Set TYPE = LINEAR
    Set INPUT-TYPE = DATA
    Set INDEPENDENT = (1, 2)
    Set DEPENDENT = (22, 44)
    Set "Baseline CW Pump Power" = CURVE-FIT
    Set TYPE = LINEAR
    Set INPUT-TYPE = DATA
    Set INDEPENDENT = (1, 2)
    Set DEPENDENT = (19.6, 39.1)

IF "Peak Cooling" <= 1055 kW *//req. G3.1.3.7 per Table G3.1.3.7*
    Insert Chiller Loop Pump under Pumps
        Set "Baseline Chiller CHW Pump" = PUMP
        IF "Building Area" > 119996, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.10*
        ELSE set CAP-CTRL = ONE-SPEED-PUMP
        Set PUMP-HP-FLOW = "Baseline CHW Pump Power" *//req. G3.1.3.10*
    Insert Chiller Loop under Circulation Loops:
        Set "Baseline Chiller CHW Loop" = CIRCULATION-LOOP
        Set TYPE = CHW
        Set DESIGN-COOL-T = 44 *//req. G3.1.3.8*
        Set LOOP-DESIGN-DT = 11.34 *//req. G3.1.3.9*
        Set COOL-SETPT-CTRL = OA-RESET
        Set COOL-RESET-SCH = "Baseline Chiller Reset"
        Set LOOP-PUMP = "Baseline Chiller CHW Pump"
    Insert Chiller under Chillers:
        Set "Chiller 1" = CHILLER
        Set TYPE = ELEC-SCREW
        IF "Peak Cooling" < 264 kW, set ELEC-INPUT-RATIO = 0.2218
        ELSE IF "Peak Cooling" >= 264 kW AND < 528 kW, set ELEC-INPUT-RATIO = 0.2204

ELSE set ELEC-INPUT-RATIO = 0.1934
Set CHW-LOOP = "Baseline Chiller CHW Loop"
Set CONDENSER-TYPE = WATER-COOLED
Set CW-LOOP = "Baseline CW Loop"
ELSE IF "Peak Cooling" > 1055 kW AND < 2110 kW *//req. G3.1.3.7 per Table G3.1.3.7*
Insert Chiller Loop Pump under Pumps
Set "Baseline Chiller CHW Pump" = PUMP
IF "Building Area" > 119996, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.10*
ELSE set CAP-CTRL = ONE-SPEED-PUMP
Set PUMP-HP-FLOW = "Baseline CHW Pump Power" *//req. G3.1.3.10*
Insert Chiller Loop under Circulation Loops:
Set "Baseline Chiller CHW Loop" = CIRCULATION-LOOP
Set TYPE = CHW
Set DESIGN-COOL-T = 44 *//req. G3.1.3.8*
Set LOOP-DESIGN-DT = 11.34 *//req. G3.1.3.9*
Set COOL-SETPT-CTRL = OA-RESET
Set COOL-RESET-SCH = "Baseline Chiller Reset"
Set LOOP-PUMP = "Baseline Chiller CHW Pump"
Insert Chiller under Chillers:
Set "Chiller 1" = CHILLER *//req. G3.1.3.7 per Table G3.1.3.7*
Set TYPE = ELEC-SCREW
Set ELEC-INPUT-RATIO = 0.1934
Set CHW-LOOP = "Baseline Chiller CHW Loop"
Set CW-LOOP = "Baseline CW Loop"
Set "Chiller 2" = CHILLER
Set TYPE = ELEC-SCREW
Set ELEC-INPUT-RATIO = 0.1934
Set CHW-LOOP = "Baseline Chiller CHW Loop"
Set CW-LOOP = "Baseline CW Loop"
ELSE
Insert Chiller Loop Pump under Pumps
Set "Chiller CHW Pump" = PUMP
IF "Building Area" > 119996, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.10*
ELSE set CAP-CTRL = ONE-SPEED-PUMP
Set PUMP-HP-FLOW = "CHW Pump Power" *//req. G3.1.3.10*
Insert Chiller Loop under Circulation Loops:
Set "Baseline Chiller CHW Loop" = CIRCULATION-LOOP
Set TYPE = CHW
Set DESIGN-COOL-T = 44 *//req. G3.1.3.8*
Set LOOP-DESIGN-DT = 11.34 *//req. G3.1.3.9*
Set COOL-SETPT-CTRL = OA-RESET
Set COOL-RESET-SCH = "Baseline Chiller Reset"
Set LOOP-PUMP = "Baseline Chiller CHW Pump"
Insert Chiller under Chillers:
IF "Peak Cooling" > 5626 kW, calculate "Number of Chillers" *//per Table G3.1.3.7*
"Number of Chillers" = "Peak Cooling" / 2813 kW, round up to nearest whole number
Input following as loop where XX (in "Chiller XX") is an incremental count of chillers

until XX = "Number of Chillers"
Set "Chiller XX" = CHILLER
Set TYPE = ELEC-OPEN-CENT
Set CHW-LOOP = "Baseline Chiller CHW Loop"
Set CONDENSER-TYPE = WATER-COOLED
Set CW-LOOP = "Baseline CW Loop"
ELSE *//per Table G3.1.3.7*
Set "Chiller 1" = CHILLER
Set TYPE = ELEC-OPEN-CENT
Set CHW-LOOP = "Baseline Chiller CHW Loop"
Set CONDENSER-TYPE = WATER-COOLED
Set CW-LOOP = "Baseline CW Loop"
Set "Chiller 2" = CHILLER
Set TYPE = ELEC-OPEN-CENT
Set CHW-LOOP = "Baseline Chiller CHW Loop"
Set CONDENSER-TYPE = WATER-COOLED
Set CW-LOOP = "Baseline CW Loop"

Insert Chiller Reset Schedules: *//req. G3.1.3.9*
Set "Day Baseline Chiller Reset" = DAY-SCHEDULE-PD
Set TYPE = RESET-TEMP
Set OUTSIDE-HI = 80.6
Set OUTSIDE-LO = 60.8
Set SUPPLY-HI = 44.6
Set SUPPLY-LO = 53.6
Set "Week Baseline Chiller Reset" = WEEK-SCHEDULE-PD
Set TYPE = RESET-TEMP
Set DAY-SCHEDULES = ("Day Baseline Chiller Reset", &D, &D, &D, &D, "Day Baseline Chiller Reset")
Set "Baseline Chiller Reset" = SCHEDULE-PD
Set TYPE = RESET-TEMP
Set MONTH = (12)
Set DAY = (31)
Set WEEK-SCHEDULES = ("Week Baseline Chiller Reset")

Insert Cooling Tower under Heat Rejection: *//req. G3.1.3.11*
Set "Baseline Cooling Tower" = HEAT-REJECTION
Set TYPE = OPEN-TWR
Set ELEC-INPUT-RATIO = 0.05
Set CAPACITY-CTRL = TWO-SPEED-FAN
Set RATED-APPROACH = 10.04
Set RATED-WETBULB = 84.2
Set CW-LOOP = "Baseline CW Loop"

Insert Cooling Tower Pump under Pumps:
Set "Baseline CW Pump" = PUMP
Set PUMP-HP-FFLOW = "Baseline CW Pump Power"

Insert Cooling Tower Circulation Loop under Circulation Loops:
Set "Baseline CW Loop" = CIRCULATION-LOOP

Set TYPE = CW
Set LOOP-PUMP = “Baseline CW Pump”

Insert Boiler Pump under Pumps:
Set “Baseline Boiler Pump” = PUMP
IF “Building Area” > 120125, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.5*
ELSE set CAP-CTRL = ONE-SPEED-PUMP
Set PUMP-HP-FLOW = “Baseline HW Pump Power” *//req. G3.1.3.5*
Insert Boiler Loop under Circulation Loops:
Set “Baseline Boiler Loop” = CIRCULATION-LOOP
Set TYPE = HW
Set LOOP-OPERATION = STANDBY
Set LOOP-DESIGN-DT = 50.4 *//req. G3.1.3.3*
Set HEAT-SETPT-CTRL = OA-RESET *//req. G3.1.3.4*
Set HEAT-SETPT-SCH = “Baseline Boiler Reset”
Set LOOP-PUMP = “Baseline Boiler Pump”
Insert Boiler under Boilers:
Set “Baseline Boiler 1” = BOILER
Set TYPE = HW-BOILER
IF “Peak Heating” < 733 kW, set HEAT-INPUT-RATIO = 1.25 *//req. G3.1.2.1*
ELSE set HEAT-INPUT-RATIO = 1.22
Set HW-LOOP = “Baseline Boiler Loop”
Set AQUASTAT-SETPT-T = 180 *//req. G3.1.3.3*
IF “Building Area” >15,069 *//req. G3.1.3.2*
Set “Baseline Boiler 2” = BOILER
Set TYPE = HW-BOILER
IF “Peak Heating” < 733, set HEAT-INPUT-RATIO = 1.25 *//req. G3.1.2.1*
ELSE set HEAT-INPUT-RATIO = 1.22
Set HW-LOOP = “Baseline Boiler Loop”
Set AQUASTAT-SETPT-T = 180 *//req. G3.1.3.3*
Insert Boiler Reset Schedules:
Set “Day Baseline Boiler Reset” = DAY-SCHEDULE-PD *//req. G3.1.3.4*
Set TYPE = RESET-TEMP
Set OUTSIDE-HI = 50
Set OUTSIDE-LO = 19.4
Set SUPPLY-HI = 180
Set SUPPLY-LO = 151
Set “Week Baseline Boiler Reset” = WEEK-SCHEDULE-PD
Set TYPE = RESET-TEMP
Set DAY-SCHEDULES = (“Day Baseline Boiler Reset”, &D, &D, &D, &D, “Day Baseline Boiler Reset”)
Set “Baseline Boiler Reset” = SCHEDULE-PD
Set TYPE = RESET TEMP
Set MONTH = (12)
Set DAY = (31)
Set WEEK-SCHEDULES = (“Week Baseline Boiler Reset”)

Insert VAV Fan Performance Curve *//req. G3.1.3.15*
Set "Baseline Part-Load Fan Power" = CURVE-FIT
Set TYPE = CUBIC
Set INPUT-TYPE = COEFFICIENTS
Set COEFFICIENTS = (0.0013, 0.147, 0.9506, 0.0998)

Review all SYSTEM
Set TYPE = VAVS *//per Table G3.1.1B*
Set COOL-CONTROL = WARMEST *//for req. G3.1.3.12*
Set COOL-SIZING-RATI = 1.15 *//req. G3.1.2.2*
Set COOL-MAX-RESET-T = 59.1 *//req. G3.1.3.12*
Set HEAT-SOURCE = HOT-WATER *//per Table G3.1.1B*
Set ZONE-HEAT-SOURCE = HOT-WATER *//per Table G3.1.1B*
Set BASEBOARD-SOURCE = NONE
Set HEAT-CONTROL = CONSTANT
Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*
Set HW-LOOP = "Baseline Boiler Loop" *//per Table G3.1.1B*
Set CHW-LOOP = "Baseline Chiller CHW Loop" *//per Table G3.1.1B*
Set OA-CONTROL = OA-TEMP *//req. G3.1.2.7*
Set ECONO-LIMIT-T = 70 *//req. G3.1.2.8*
Set MAX-OA-FRACTION = 1.0
Set FAN-CONTROL = FAN-EIR-FPLR *//req. G3.1.3.15*
Set FAN-EIR-FPLR = "Baseline Part-Load Fan Power"
Set REHEAT-DELTA-T = 18

Review all ZONE where TYPE = CONDITIONED
Set TERMINAL-TYPE = SVAV *//per Table G3.1.1B*
For corresponding SPACE
Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**
Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*
Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*
Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*
IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*
IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*
IF NUMBER-OF-PEOPLE =/ "undefined"
Calculate design outdoor air flow ("Design OA")
"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x NUMBER-OF-PEOPLE
Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")
*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x NUMBER-OF-PEOPLE*
ELSE
Calculate Occupancy ("Occupancy")

"Occupancy" = 1 / (AREA/PERSON) x "Space Area"

Calculate design outdoor air flow ("Design OA")

"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x "Occupancy"

Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")

"ASHRAE OA" = ***"CFM/ft2"*** *x "Space Area" +* ***"CFM/Person"*** *x "Occupancy"*

Calculate "Air Flow Rate" *//req. G3.1.2.9.1*

*"Air Flow Rate" = [("Space Cooling" / (1.02 kg/m^3 x 1.2 kJ/kg x 11.1 K))*1.15] * 2,118.8*

IF "Air Flow Rate" > "ASHRAE OA", set FLOW/AREA = ("Air Flow Rate" / "Space Area")

ELSE set FLOW/AREA = ("ASHRAE OA" / "Space Area")

Calculate design air flow ("Design Flow")

*"Design Flow" = FLOW/AREA * "Space Area"*

Set MIN-FLOW-RATIO = 0.3 *//req. G3.1.3.13*

Review all SYSTEM

IF RETURN-FLOW =/ "undefined" *//req. G3.1.2.9.1*

Review corresponding ZONEs

IF ("Design Flow" – "ASHRAE OA") > ("Design Flow" x 0.9), set RETURN-FLOW = ("Design Flow" – "ASHRAE OA")

ELSE set RETURN-FLOW = ("Design Flow" x 0.9)

For corresponding ZONEs

Sum "Design Flow", convert to metric ("Design Flow L/s")

"Design Flow L/s" = SUPPLY-FLOW [CFM] / 2.1188

Calculate Input kW ("Input kW") *//req. G3.1.2.10*

*"Input kW" = "Design Flow L/s" * 0.0021 + SUPPLY-STATIC x 250*

Find **"Fan Motor Efficiency" value** of **HVAC Equipment: ASHRAE Table 10.8B** for "Input kW", using closest "**Motor Input kW" value** > "Input kW"

Set SUPPLY-MTR-EFF = **"Fan Motor Efficiency"**

‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA ("% OA")

"% OA" = Sum "Design OA" / Sum SUPPLY-FLOW

IF "% OA" < 0.3, set RECOVER-EXHAUST = NO

ELSE Find "% OA" on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **">=" and "<" values**

IF SUPPLY-FLOW >= **"Design Supply Airflow Rate" value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at "*Service Hot Water*" on page B-37

System 8 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components ("Peak Cooling") *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components ("Peak Heating") *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP
    IF TYPE =/ DHW, remove all inputs *//removes unused inputs, leaves DHW*

Insert Pump Power Curve under Performance Curves:
    Set "Baseline CHW Pump Power" = CURVE-FIT *//for req. G3.1.3.10*
    Set TYPE = LINEAR
    Set INPUT-TYPE = DATA
    Set INDEPENDENT = (1, 2)
    Set DEPENDENT = (22, 44)
    Set "Baseline CW Pump Power" = CURVE-FIT
    Set TYPE = LINEAR
    Set INPUT-TYPE = DATA
    Set INDEPENDENT = (1, 2)
    Set DEPENDENT = (19.6, 39.1)

IF "Peak Cooling" <= 1055 kW *//req. G3.1.3.7 per Table G3.1.3.7*
    Insert Chiller Loop Pump under Pumps
        Set "Baseline Chiller CHW Pump" = PUMP
        IF "Building Area" > 119996, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.10*
        ELSE set CAP-CTRL = ONE-SPEED-PUMP
        Set PUMP-HP-FLOW = "Baseline CHW Pump Power" *//req. G3.1.3.10*
    Insert Chiller Loop under Circulation Loops:
        Set "Baseline Chiller CHW Loop" = CIRCULATION-LOOP
        Set TYPE = CHW
        Set DESIGN-COOL-T = 44 *//req. G3.1.3.8*
        Set LOOP-DESIGN-DT = 11.34 *//req. G3.1.3.9*
        Set COOL-SETPT-CTRL = OA-RESET
        Set COOL-RESET-SCH = "Baseline Chiller Reset"
        Set LOOP-PUMP = "Baseline Chiller CHW Pump"
    Insert Chiller under Chillers:
        Set "Chiller 1" = CHILLER
        Set TYPE = ELEC-SCREW
        IF "Peak Cooling" < 264 kW, set ELEC-INPUT-RATIO = 0.2218
        ELSE IF "Peak Cooling" >= 264 kW AND < 528 kW, set ELEC-INPUT-RATIO = 0.2204
        ELSE set ELEC-INPUT-RATIO = 0.1934
        Set CHW-LOOP = "Baseline Chiller CHW Loop"
        Set CONDENSER-TYPE = WATER-COOLED
        Set CW-LOOP = "Baseline CW Loop"
ELSE IF "Peak Cooling" > 1055 kW AND < 2110 kW *//req. G3.1.3.7 per Table G3.1.3.7*

Insert Chiller Loop Pump under Pumps
Set “Baseline Chiller CHW Pump” = PUMP
IF “Building Area” > 119996, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.10*
ELSE set CAP-CTRL = ONE-SPEED-PUMP
Set PUMP-HP-FLOW = “Baseline CHW Pump Power” *//req. G3.1.3.10*
Insert Chiller Loop under Circulation Loops:
Set “Baseline Chiller CHW Loop” = CIRCULATION-LOOP
Set TYPE = CHW
Set DESIGN-COOL-T = 44 *//req. G3.1.3.8*
Set LOOP-DESIGN-DT = 11.34 *//req. G3.1.3.9*
Set COOL-SETPT-CTRL = OA-RESET
Set COOL-RESET-SCH = “Baseline Chiller Reset”
Set LOOP-PUMP = “Baseline Chiller CHW Pump”
Insert Chiller under Chillers:
Set “Chiller 1” = CHILLER *//req. G3.1.3.7 per Table G3.1.3.7*
Set TYPE = ELEC-SCREW
Set ELEC-INPUT-RATIO = 0.1934
Set CHW-LOOP = “Baseline Chiller CHW Loop”
Set CW-LOOP = “Baseline CW Loop”
Set “Chiller 2” = CHILLER
Set TYPE = ELEC-SCREW
Set ELEC-INPUT-RATIO = 0.1934
Set CHW-LOOP = “Baseline Chiller CHW Loop”
Set CW-LOOP = “Baseline CW Loop”
ELSE
Insert Chiller Loop Pump under Pumps
Set “Chiller CHW Pump” = PUMP
IF “Building Area” > 119996, set CAP-CTRL = VAR-SPEED-PUMP *//req. G3.1.3.10*
ELSE set CAP-CTRL = ONE-SPEED-PUMP
Set PUMP-HP-FLOW = “CHW Pump Power” *//req. G3.1.3.10*
Insert Chiller Loop under Circulation Loops:
Set “Baseline Chiller CHW Loop” = CIRCULATION-LOOP
Set TYPE = CHW
Set DESIGN-COOL-T = 44 *//req. G3.1.3.8*
Set LOOP-DESIGN-DT = 11.34 *//req. G3.1.3.9*
Set COOL-SETPT-CTRL = OA-RESET
Set COOL-RESET-SCH = “Baseline Chiller Reset”
Set LOOP-PUMP = “Baseline Chiller CHW Pump”
Insert Chiller under Chillers:
IF “Peak Cooling” > 5626 kW, calculate “Number of Chillers” *//per Table G3.1.3.7*
“Number of Chillers” = “Peak Cooling” / 2813 kW, round up to nearest whole number
Input following as loop where XX (in “Chiller XX”) is an incremental count of chillers until XX = “Number of Chillers”
Set “Chiller XX” = CHILLER
Set TYPE = ELEC-OPEN-CENT
Set CHW-LOOP = “Baseline Chiller CHW Loop”
Set CONDENSER-TYPE = WATER-COOLED

Set CW-LOOP = “Baseline CW Loop”
ELSE *//per Table G3.1.3.7*
Set “Chiller 1” = CHILLER
Set TYPE = ELEC-OPEN-CENT
Set CHW-LOOP = “Baseline Chiller CHW Loop”
Set CONDENSER-TYPE = WATER-COOLED
Set CW-LOOP = “Baseline CW Loop”
Set “Chiller 2” = CHILLER
Set TYPE = ELEC-OPEN-CENT
Set CHW-LOOP = “Baseline Chiller CHW Loop”
Set CONDENSER-TYPE = WATER-COOLED
Set CW-LOOP = “Baseline CW Loop”
Insert Chiller Reset Schedules: *//req. G3.1.3.9*
Set “Day Baseline Chiller Reset” = DAY-SCHEDULE-PD
Set TYPE = RESET-TEMP
Set OUTSIDE-HI = 80.6
Set OUTSIDE-LO = 60.8
Set SUPPLY-HI = 44.6
Set SUPPLY-LO = 53.6
Set “Week Baseline Chiller Reset” = WEEK-SCHEDULE-PD
Set TYPE = RESET-TEMP
Set DAY-SCHEDULES = (“Day Baseline Chiller Reset”, &D, &D, &D, &D, “Day Baseline Chiller Reset”)
Set “Baseline Chiller Reset” = SCHEDULE-PD
Set TYPE = RESET-TEMP
Set MONTH = (12)
Set DAY = (31)
Set WEEK-SCHEDULES = (“Week Baseline Chiller Reset”)

Insert Cooling Tower under Heat Rejection: *//req. G3.1.3.11*
Set “Baseline Cooling Tower” = HEAT-REJECTION
Set TYPE = OPEN-TWR
Set ELEC-INPUT-RATIO = 0.05
Set CAPACITY-CTRL = TWO-SPEED-FAN
Set RATED-APPROACH = 10.04
Set RATED-WETBULB = 84.2
Set CW-LOOP = “Baseline CW Loop”
Insert Cooling Tower Pump under Pumps:
Set “Baseline CW Pump” = PUMP
Set PUMP-HP-FFLOW = “Baseline CW Pump Power”
Insert Cooling Tower Circulation Loop under Circulation Loops:
Set “Baseline CW Loop” = CIRCULATION-LOOP
Set TYPE = CW
Set LOOP-PUMP = “Baseline CW Pump”

Insert VAV Fan Performance Curve *//req. G3.1.3.15*
Set “Baseline Part-Load Fan Power” = CURVE-FIT

Set TYPE = CUBIC
Set INPUT-TYPE = COEFFICIENTS
Set COEFFICIENTS = (0.0013, 0.147, 0.9506, 0.0998)

Review all SYSTEM
Set TYPE = PIU *//per Table G3.1.1B*
Set COOL-SOURCE = CHILLED-WATER *//per Table G3.1.1B*
Set COOL-CONTROL = WARMEST *//for req. G3.1.3.12*
Set CONDENSER-TYPE = WATER-COOLED
Set COOL-SIZING-RATI = 1.15 *//req. G3.1.2.2*
Set COOL-MAX-RESET-T = 59.1 *//req. G3.1.3.12*
Set HEAT-SOURCE = ELECTRIC *//per Table G3.1.1B*
Set ZONE-HEAT-SOURCE = ELECTRIC *//per Table G3.1.1B*
Set BASEBOARD-SOURCE = NONE
Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*
Set HEAT-CONTROL = CONSTANT
Set CHW-VALVE-TYPE = THREE-WAY
Set CHW-LOOP = "Baseline Chiller CHW Loop" *//per Table G3.1.1B*
Set CW-LOOP = "Baseline CW Loop"
Set OA-CONTROL = OA-TEMP *//req. G3.1.2.7*
Set ECONO-LIMIT-T = 70 *//req. G3.1.2.8*
Set MAX-OA-FRACTION = 1.0
Set FAN-CONTROL = FAN-EIR-FPLR *//req. G3.1.3.15*
Set FAN-EIR-FPLR = "Baseline Part-Load Fan Power"
Set REHEAT-DELTA-T = 18

Review all ZONE where TYPE = CONDITIONED
Set TERMINAL-TYPE = PARALLEL-PIU *//per Table G3.1.1B*
Set ZONE-FAN-RUN = HEATING-ONLY
Set ZONE-FAN-CTRL = VARIABLE-VOLUME *//per Table G3.1.1B*
Set ZONE-FAN-KW/FLOW = 0.000349 *//req. G3.1.3.14*
Set ZONE-FAN-RATIO = 0.5 *//req. G3.1.3.14*
For corresponding SPACE
Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**
Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*
Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*
Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*
IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*
IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*
IF NUMBER-OF-PEOPLE =/ "undefined"
Calculate design outdoor air flow ("Design OA")

"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x NUMBER-OF-PEOPLE
Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")
*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x NUMBER-OF-PEOPLE*
ELSE
Calculate Occupancy ("Occupancy")
"Occupancy" = 1 / (AREA/PERSON) x "Space Area"
Calculate design outdoor air flow ("Design OA")
"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x "Occupancy"
Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")
*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x "Occupancy"*
Calculate "Air Flow Rate" *//req. G3.1.2.9.1*
*"Air Flow Rate" = [("Space Cooling" / (1.02 kg/m^3 x 1.2 kJ/kg x 11.1 K))*1.15] * 2,118.8*
IF "Air Flow Rate" > "ASHRAE OA", set FLOW/AREA = ("Air Flow Rate" / "Space Area")
ELSE set FLOW/AREA = ("ASHRAE OA" / "Space Area")
Calculate design air flow ("Design Flow")
*"Design Flow" = FLOW/AREA * "Space Area"*
Set MIN-FLOW-RATIO = 0.3 *//req. G3.1.3.14*

Review all SYSTEM
IF RETURN-FLOW =/ "undefined" *//req. G3.1.2.9.1*
Review corresponding ZONEs
IF ("Design Flow" – "ASHRAE OA") > ("Design Flow" x 0.9), set RETURN-FLOW = ("Design Flow" – "ASHRAE OA")
ELSE set RETURN-FLOW = ("Design Flow" x 0.9)
For corresponding ZONEs
Sum "Design Flow", convert to metric ("Design Flow L/s")
"Design Flow L/s" = SUPPLY-FLOW [CFM] / 2.1188
Calculate Input kW ("Input kW") *//req. G3.1.2.10*
*"Input kW" = "Design Flow L/s" * 0.0021 + SUPPLY-STATIC x 250*
Find **"Fan Motor Efficiency" value** of **HVAC Equipment: ASHRAE Table 10.8B** for "Input kW", using closest "**Motor Input kW" value** > "Input kW"
Set SUPPLY-MTR-EFF = **"Fan Motor Efficiency"**
‡ For corresponding ZONEs *//req. G3.1.2.11*
IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO
ELSE Calculate Total % OA ("% OA")
"% OA" = Sum "Design OA" / Sum SUPPLY-FLOW
IF "% OA" < 0.3, set RECOVER-EXHAUST = NO
ELSE Find "% OA" on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **">=" and "<" values**
IF SUPPLY-FLOW >= **"Design Supply Airflow Rate" value**, set RECOVER-EXHAUST = YES
IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5
Continue at "*Service Hot Water*" on page B-37

†System 9 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components ("Peak Cooling") *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components ("Peak Heating") *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP *//removes unused inputs, leaves DHW*

IF TYPE =/ DHW, remove all inputs

Review all SYSTEM

† Set TYPE = HVSYS *//per Table G3.1.1B*

Set HEAT-SOURCE = FURNACE *//per Table G3.1.1B*

Set ZONE-HEAT-SOURCE = NONE

Set BASEBOARD-SOURCE = NONE

Set FURNACE-HIR = 1.25 *//req. G3.1.2.1*

Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*

Set FURNACE-HIR-FPLR = Furnace-HIR-fPLR

Set OA-CONTROL = FIXED *//req. G3.1.2.7*

Set MAX-OA-FRACTION = 1.0

Set FAN-CONTROL = CONSTANT-VOLUME *//per Table G3.1.1B*

Review all ZONE where TYPE = CONDITIONED

For corresponding SPACE

Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**

Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*

Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*

Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*

IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*

IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*

IF NUMBER-OF-PEOPLE =/ "undefined"

Calculate design outdoor air flow ("Design OA")

"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x NUMBER-OF-PEOPLE

Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")

*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x NUMBER-OF-PEOPLE*

ELSE

Calculate Occupancy ("Occupancy")

"Occupancy" = 1 / (AREA/PERSON) x "Space Area"

Calculate design outdoor air flow ("Design OA")

"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x "Occupancy"

Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")

"ASHRAE OA" = ***"CFM/ft2"*** *x "Space Area" +* ***"CFM/Person"*** *x "Occupancy"*

Calculate "Air Flow Rate" *//req. G3.1.2.9.2*

*"Air Flow Rate" = [("Space Heating" / (1.02 kg/m^3 x 1.2 kJ/kg x 58.3 K))*1.25] * 2,118.8*

IF "Air Flow Rate" > "ASHRAE OA", set FLOW/AREA = ("Air Flow Rate" / "Space Area")

ELSE set FLOW/AREA = ("ASHRAE OA" / "Space Area")

Calculate design air flow ("Design Flow")

*"Design Flow" = FLOW/AREA * "Space Area"*

Review all SYSTEM

Set SUPPLY-KW/FLOW = 0.64 *//req. G3.1.2.10*

Remove SUPPLY-STATIC input

‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA ("% OA")

"% OA" = Sum "Design OA" / Sum SUPPLY-FLOW

IF "% OA" < 0.3, set RECOVER-EXHAUST = NO

ELSE Find "% OA" on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **">=" and "<" values**

IF SUPPLY-FLOW >= **"Design Supply Airflow Rate" value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at "*Service Hot Water*" on page B-37

†System 10 Process

Extract TOTAL LOAD : COOLING (KW) from Report LS-C Building Peak Load Components ("Peak Cooling") *//used for selecting cooling equipment efficiency*

Extract TOTAL LOAD : HEATING (KW) from Report LS-C Building Peak Load Components ("Peak Heating") *//used for selecting heating equipment efficiency*

Remove all inputs under Pumps, Heat Exchangers, Chillers, Boilers, Heat Rejection, Tower Free Cooling, Electric Generators, Thermal Storage, Ground Loop Heat Exchangers *//removes unused inputs*

Review all CIRCULATION-LOOP *//removes unused inputs, leaves DHW*
IF TYPE =/ DHW, remove all inputs

Review all SYSTEM
† Set TYPE = HVSYS *//per Table G3.1.1B*
Set HEAT-SOURCE = ELECTRIC *//per Table G3.1.1B*
Set ZONE-HEAT-SOURCE = NONE
Set BASEBOARD-SOURCE = NONE
Set HEAT-SIZING-RATI = 1.25 *//req. G3.1.2.2*
Set OA-CONTROL = FIXED *//req. G3.1.2.7*
Set MAX-OA-FRACTION = 1.0
Set FAN-CONTROL = CONSTANT-VOLUME *//per Table G3.1.1B*

Review all ZONE where TYPE = CONDITIONED
For corresponding SPACE
Find C-ACTIVITY-DESC in **Ventilation: Ventilation by Space Type Table** under **"eQuest Activity Area Type"**
Extract **"CFM/Person" value** and **"CFM/ft2" value** *//determine ASHRAE 62.1 requirements*
Extract TOTAL LOAD : COOLING (KW) from Report LS-B Space Peak Load Components ("Space Cooling") *//used for req. G3.1.2.9.1*
Extract FLOOR AREA (SQFT) from Report LS-B Space Peak Load Components ("Space Area" *//used to calculate outdoor air requirement and design*
IF OA-FLOW/AREA > **"CFM/ft2" value**, set OA-FLOW/AREA = **"CFM/ft2" value** *//req. G3.1.2.6*
IF OA-FLOW/PER > **"CFM/Person" value**, set OA-FLOW/PER = **"CFM/Person" value** *//req. G3.1.2.6*
IF NUMBER-OF-PEOPLE =/ "undefined"
Calculate design outdoor air flow ("Design OA")
"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x NUMBER-OF-PEOPLE
Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")
*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x NUMBER-OF-PEOPLE*
ELSE
Calculate Occupancy ("Occupancy")
"Occupancy" = 1 / (AREA/PERSON) x "Space Area"
Calculate design outdoor air flow ("Design OA")
"Design OA" = OA-FLOW/AREA x "Space Area" + OA-FLOW/PER x "Occupancy"
Calculate ASHRAE minimum outdoor air requirement ("ASHRAE OA")
*"ASHRAE OA" = **"CFM/ft2"** x "Space Area" + **"CFM/Person"** x "Occupancy"*

Calculate “Air Flow Rate” *//req. G3.1.2.9.2*

*“Air Flow Rate” = [(“Space Heating” / (1.02 kg/m³ x 1.2 kJ/kg x 58.3K))*1.25] * 2,118.8*

IF “Air Flow Rate” > “ASHRAE OA”, set FLOW/AREA = (“Air Flow Rate” / “Space Area”)

ELSE set FLOW/AREA = (“ASHRAE OA” / “Space Area”)

Calculate design air flow (“Design Flow”)

*“Design Flow” = FLOW/AREA * “Space Area”*

Review all SYSTEM

Set SUPPLY-KW/FLOW = 0.64 *//req. G3.1.2.10*

Remove SUPPLY-STATIC input

‡ For corresponding ZONEs *//req. G3.1.2.11*

IF DESIGN-HEAT-T < 61, set RECOVER-EXHAUST = NO

ELSE Calculate Total % OA (“% OA”)

“% OA” = Sum “Design OA” / Sum SUPPLY-FLOW

IF “% OA” < 0.3, set RECOVER-EXHAUST = NO

ELSE Find “% OA” on **HVAC Equipment: ASHRAE Table 6.5.6.1** between **“>=” and “<” values**

IF SUPPLY-FLOW >= **“Design Supply Airflow Rate” value**, set RECOVER-EXHAUST = YES

IF RECOVER-EXHAUST = YES, set ERV-RECOVER-TYPE = SENSIBLE-WHEEL, AND set ERV-SENSIBLE-EFF = 0.5

Continue at “*Service Hot Water*” on page B-37

Service Hot Water
Find DW-HEATER
Insert TYPE, CAPACITY, and TANK-VOLUME into **DHW: Domestic Water Heater Table**
IF TYPE = HEAT-PUMP, set TYPE = ELECTRIC *//per Table G3.1.11-b*
IF TYPE = GAS *//assigns efficiency and standby loss per Table 7.8*
IF CAPACITY <= 0.0784, set HEAT-INPUT-RATIO = **"DHW Heat Input Ratio" value**
ELSE set HEAT-INPUT-RATIO = **"DHW Heat Input Ratio" value** and set TANK-UA = **"Heat Transfer Coefficient (UA)" value**
ELSE *//assigns efficiency and standby loss per Table 7.8*
IF CAPACITY <= 0.04094, set ELEC-INPUT-RATIO = **"DHW Electric Input Ratio" value**
ELSE set TANK-UA = **"Heat Transfer Coefficient (UA)" value**

Orientations *//per Table G3.1.5-a*
Save new version of "Baseline.inp" as "Baseline+90.inp"
For BUILD-PARAMETERS, set AZIMUTH = x + 90, where x is the current value
Save new version of "Baseline.inp" as "Baseline+180.inp"
For BUILD-PARAMETERS, set AZIMUTH = x + 180, where x is the current value
Save new version of "Baseline.inp" as "Baseline+270.inp"
For BUILD-PARAMETERS, set AZIMUTH = x + 270, where x is the current value

Appendix C – OBC Baseline Decision-making Process

This document outlines the eQUEST inputs and input substitutions needed to generate an OBC Baseline building from an uploaded eQUEST input file. The algorithm is written in illustrative pseudo-code to show the decision-making process, intended to facilitate software development. Full software code development is outside of the scope of this project.

Many of the requirements for the OBC Baseline match the requirements of the ASHRAE Baseline building. The algorithm presented below is intended to supersede the first two sections of Appendix B – ASHRAE Baseline Decision-making Process. Where indicated, the algorithm continues with Appendix B, substituting “OBC-Baseline.inp” for “Baseline.inp”.

Contents

Key: Bolded references (“**Table X**”) refer to Appendix A – Calculations and eQUEST Inputs for Baseline Creation, Program Screening, and Database Creation
eQUEST inputs are referenced using their Keyword and/or Command in CAPS
Tool inputs are defined using quotation marks
Explanatory comments and references to ASHRAE 90.1 requirements are marked with // and written in dark grey

Initial Set-up
User uploads eQUEST input file (.inp) for proposed building (“Proposed.inp”)
User selects “Building Type”, “Project Stage”, “Heating Fuel”, and “Cooling”
IF “Project Stage” = Completed Building, User inputs “Postal Code”, and “Year of Completion”
User inputs “# Floors”, “Renewable Electricity Generation – On-site”, “Renewable Electricity Generation – Off-site”, and “Sale Price of On-site Energy Generation”
Save new version as “OBC-Baseline.inp”

IF “Heating Fuel” = “Electric”, continue below; ELSE skip to page C-6

Envelope – Electric

Window-Wall Ratio and Skylight-Roof Ratio

```
Run eQUEST simulation for “Baseline.inp”
Open Report LV-D Details of Exterior Surfaces in “Baseline.sim” //calculate WWR of proposed
   For ALL WALLS
      “Total.WWR” = WINDOW AREA x 100 / WINDOW+WALL AREA
   For ROOF
      “Skylight.Ratio” = WINDOW AREA x 100 / WINDOW+WALL AREA
//reduce window area to maximum 40% WWR
IF “Total.WWR” > 40
   Set “WWR.Fraction” = 40 / “Total.WWR”
   For each Surface where AZIMUTH != ROOF or UNDERGRND, add to “Wall.Surface” list
   Open Report LV-C Details of Space
      For each Surface in “Wall.Surface” list
         Select all WINDOWS and add window U-NAME to “Wall.Window” list
   Close Report LV-C Details of Space
   Open “Baseline.inp”
      For each WINDOW where U-NAME is in “Wall.Window” list
                     WIDTH_Reduced = “WWR.Fraction” x WIDTH
         WIDTH = WIDTH_Reduced

//reduce skylight area to maximum 5% of roof
IF “Skylight.Ratio” > 5
   Set “Skylight.Fraction” = 5 / “Skylight.Ratio”
   For each Surface where AZIMUTH = ROOF, add to “Roof.Surface” list
   Open Report LV-C Details of Space
      For each Surface in “Roof.Surface” list
         Select all WINDOWS and add window U-NAME to “Roof.Window” list
   Close Report LV-C Details of Space
   Open “Baseline.inp”
      For each WINDOW where U-NAME is in “Roof.Window” list
                     WIDTH_Reduced = “Skylight.Fraction” x WIDTH
         WIDTH = WIDTH_Reduced
Close Report LV-D Details of Exterior Surfaces
```

Infiltration

For each SPACE in “OBC-Baseline.inp” *//sets air infiltration to 0.2 L/s-m^2*

Set INF-METHOD = AIR-CHANGE

Remove input AIR-CHANGES/HR

Set INF-FLOW/AREA = 0.0124

Opaque Assemblies

Review all FLOORs in “OBC-Baseline.inp” *//calculates the R-effective of exposed underground surface*

IF any Z < 0, insert label in the FLOOR where Z is closest to Z = 0 (while still Z < 0) as “$ perim-exposed” *//means the exposed underground surface is a wall*

ELSE insert label in the FLOOR where Z = 0 as “$ slab-perim-exposed” *//means exposed underground surface is the slab-on-grade*

Calculate area of FLOOR labelled “$ perim-exposed” or “$ slab-perim-exposed”, using POLYGON

Calculate the perimeter of FLOOR labelled “$ perim-exposed” or “$ slab-perim-exposed”

IF label = “$ perim-exposed” *//calculates the underground wall R-effective value*

Insert FLOOR Area and FLOOR Perimeter in **Envelope Calculations: Underground Surfaces Calculations Table** under **“$ perim-exposed” heading**

Insert all “R-fictitious” values in **Envelope -Opaque** under **“BG Wall Rfic – Exposed: RESISTANCE” heading**

ELSE *//calculates the slab R-effective value*

Insert FLOOR Area and FLOOR Perimeter in **Envelope Calculations: Underground Surfaces Calculations Table** under **“$ slab-perim-exposed” heading**

Insert all “R-fictitious” values in **Envelope -Opaque** under **“Slab Rfic – Exposed: RESISTANCE” heading**

Find “Building Type” in **Envelope Calculations: Building Type Table** *//inserts the envelope inputs based on building type*

IF “**Baseline” heading** value = Nonresidential, insert all inputs under “**Nonresidential” heading** in **Envelope -Opaque: OBC SB-10 Climate Zone 7 Table**

Define string *XXX* = “Nonres”

ELSE insert all inputs under “**Residential” heading** in **Envelope -Opaque: OBC SB-10 Climate Zone 7 Table**

Define string *XXX* = “Res”

Insert all inputs under **“Semiheated” heading** in **Envelope -Opaque: OBC SB-10 Climate Zone 7 Table**

Review all ZONEs *//identifies semiheated spaces*

IF DESIGN-HEAT-T < 59, search for corresponding SPACE, and insert label “$ Semiheated”

Review all EXTERIOR-WALL

IF LOCATION = TOP *//replaces roof construction with baseline construction*

IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC7-Roof-Semiheat”

ELSE set CONSTRUCTION = “OBC7-Roof-*XXX*” (using “XXX” definition above)

IF LOCATION = BOTTOM *//replaces exterior floor construction with baseline construction*

IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC7-Floor-Semiheat”

ELSE set CONSTRUCTION = “OBC7-Floor-*XXX*”

ELSE *//replaces exterior wall construction with baseline construction*

IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC7-Walls-Semiheat”
ELSE set CONSTRUCTION = “OBC7-Walls-*XXX*”
Review all UNDERGROUND-WALL
IF LOCATION = BOTTOM *//replaces slab construction with baseline construction*
IF FLOOR is labelled “$ slab-perim-exposed” *//chooses between two slab baseline constructions, exposed and regular*
IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC7-Slab-Semiheat-Exp”
ELSE set CONSTRUCTION = “OBC7-Slab-*XXX*-Exp”
ELSE IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC7-Slab-Semiheat”
ELSE set CONSTRUCTION = “OBC7-Slab-*XXX*”
ELSE IF FLOOR is labelled “$ perim-exposed” *//replaces underground wall construction with baseline construction, after choosing between two underground wall constructions, exposed and regular*
IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC7-BGWalls-Semiheat-Exp”
ELSE set CONSTRUCTION = “OBC7-BGWalls-*XXX*-Exp”
ELSE IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC7-BGWalls-Semiheat”
ELSE set CONSTRUCTION = “OBC7-BGWalls-*XXX*”
Review all DOOR *//replaces door construction with baseline construction*
IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC7-Door-Semiheat”
ELSE set CONSTRUCTION = “OBC7-Door-*XXX*”

Fenestration
Find “Building Type” in **Envelope Calculations: Building Type Table** *//inserts fenestration inputs based on building type*
IF “**Baseline” heading** value = Nonresidential, insert all inputs under “**Nonresidential” heading** in **Envelope -Fenestration: OBC SB-10 Climate Zone 7 Table**
Define string *XXX* = “Nonres”
ELSE insert all inputs under “**Residential” heading** in **Envelope -Fenestration: OBC SB-10 Climate Zone 7 Table**
Define string *XXX* = “Res”
Insert all inputs under **“Semiheated” heading** in **Envelope -Fenestration: OBC SB-10 Climate Zone 7 Table**
Review all WINDOW
IF EXTERIOR-WALL: LOCATION = TOP *//replaces skylight glass-type with baseline glass-type*
IF SPACE is labelled “$ Semiheated”, set GLASS-TYPE = “OBC7-Skylight-Semiheat”
ELSE set GLASS-TYPE = “OBC7-Skylight-*XXX*”
ELSE IF SPACE is labelled “$ Semiheated”, set GLASS-TYPE = “OBC7-Window-Semiheat” *//replaces window glass-type with baseline glass-type*
ELSE set GLASS-TYPE = “OBC7-Window-*XXX*”

From this point onward, the OBC process directly matches the ASHRAE Process, beginning from the ***"Lighting"* heading** on page B-7 of **Appendix B – ASHRAE Baseline Decision-making Process**, substituting "OBC-Baseline.inp" for "Baseline.inp".

IF “Heating Fuel” =/ “Electric”, continue below

Envelope – Fossil Fuel

Window-Wall Ratio and Skylight-Roof Ratio

Run eQUEST simulation for “Baseline.inp”

Open <u>Report LV-D Details of Exterior Surfaces</u> in “Baseline.sim” *//calculate WWR of proposed*

For ALL WALLS

“Total.WWR” = WINDOW AREA x 100 / WINDOW+WALL AREA

For ROOF

“Skylight.Ratio” = WINDOW AREA x 100 / WINDOW+WALL AREA

//reduce window area to maximum 40% WWR

IF “Total.WWR” > 40

Set “WWR.Fraction” = 40 / “Total.WWR”

For each Surface where AZIMUTH != ROOF or UNDERGRND, add to “Wall.Surface” list

Open <u>Report LV-C Details of Space</u>

For each Surface in “Wall.Surface” list

Select all WINDOWS and add window U-NAME to “Wall.Window” list

Close <u>Report LV-C Details of Space</u>

Open “Baseline.inp”

For each WINDOW where U-NAME is in “Wall.Window” list

$$WIDTH_{Reduced} = \text{“}WWR.Fraction\text{”} \times WIDTH$$

WIDTH = $WIDTH_{Reduced}$

//reduce skylight area to maximum 5% of roof

IF “Skylight.Ratio” > 5

Set “Skylight.Fraction” = 5 / “Skylight.Ratio”

For each Surface where AZIMUTH = ROOF, add to “Roof.Surface” list

Open <u>Report LV-C Details of Space</u>

For each Surface in “Roof.Surface” list

Select all WINDOWS and add window U-NAME to “Roof.Window” list

Close <u>Report LV-C Details of Space</u>

Open “Baseline.inp”

For each WINDOW where U-NAME is in “Roof.Window” list

$$WIDTH_{Reduced} = \text{“}Skylight.Fraction\text{”} \times WIDTH$$

WIDTH = $WIDTH_{Reduced}$

Close <u>Report LV-D Details of Exterior Surfaces</u>

Infiltration

For each SPACE in “OBC-Baseline.inp” *//sets air infiltration to 0.2 L/s-m²*

Set INF-METHOD = AIR-CHANGE

Remove input AIR-CHANGES/HR

Set INF-FLOW/AREA = 0.0124

Opaque Assemblies

Review all FLOORs in “OBC-Baseline.inp” *//calculates the R-effective of exposed underground surface*

IF any Z < 0, insert label in the FLOOR where Z is closest to Z = 0 (while still Z < 0) as "$ perim-exposed" *//means the exposed underground surface is a wall*

ELSE insert label in the FLOOR where Z = 0 as "$ slab-perim-exposed" *//means exposed underground surface is the slab-on-grade*

Calculate area of FLOOR labelled "$ perim-exposed" or "$ slab-perim-exposed", using POLYGON

Calculate the perimeter of FLOOR labelled "$ perim-exposed" or "$ slab-perim-exposed"

IF label = "$ perim-exposed" *//calculates the underground wall R-effective value*

Insert FLOOR Area and FLOOR Perimeter in **Envelope Calculations: Underground Surfaces Calculations Table** under **"$ perim-exposed" heading**

Insert all "R-fictitious" values in **Envelope -Opaque** under **"BG Wall Rfic – Exposed: RESISTANCE" heading**

ELSE *//calculates the slab R-effective value*

Insert FLOOR Area and FLOOR Perimeter in **Envelope Calculations: Underground Surfaces Calculations Table** under **"$ slab-perim-exposed" heading**

Insert all "R-fictitious" values in **Envelope -Opaque** under **"Slab Rfic – Exposed: RESISTANCE" heading**

Find "Building Type" in **Envelope Calculations: Building Type Table** *//inserts the envelope inputs based on building type*

IF "**Baseline" heading** value = Nonresidential, insert all inputs under "**Nonresidential" heading** in **Envelope -Opaque: OBC SB-10 Climate Zone 6 Table**

Define string *XXX* = "Nonres"

ELSE insert all inputs under "**Residential" heading** in **Envelope -Opaque: OBC SB-10 Climate Zone 6 Table**

Define string *XXX* = "Res"

Insert all inputs under **"Semiheated" heading** in **Envelope -Opaque: OBC SB-10 Climate Zone 6 Table**

Review all ZONEs *//identifies semiheated spaces*

IF DESIGN-HEAT-T < 59, search for corresponding SPACE, and insert label "$ Semiheated"

Review all EXTERIOR-WALL

IF LOCATION = TOP *//replaces roof construction with baseline construction*

IF SPACE is labelled "$ Semiheated", set CONSTRUCTION = "OBC6-Roof-Semiheat"

ELSE set CONSTRUCTION = "OBC6-Roof-*XXX*" (using "XXX" definition above)

IF LOCATION = BOTTOM *//replaces exterior floor construction with baseline construction*

IF SPACE is labelled "$ Semiheated", set CONSTRUCTION = "OBC6-Floor-Semiheat"

ELSE set CONSTRUCTION = "OBC6-Floor-*XXX*"

ELSE *//replaces exterior wall construction with baseline construction*

IF SPACE is labelled "$ Semiheated", set CONSTRUCTION = "OBC6-Walls-Semiheat"

ELSE set CONSTRUCTION = "OBC6-Walls-*XXX*"

Review all UNDERGROUND-WALL

IF LOCATION = BOTTOM *//replaces slab construction with baseline construction*

IF FLOOR is labelled "$ slab-perim-exposed" *//chooses between two slab baseline constructions, exposed and regular*

IF SPACE is labelled "$ Semiheated", set CONSTRUCTION = "OBC6-Slab-Semiheat-Exp"

ELSE set CONSTRUCTION = "OBC6-Slab-*XXX*-Exp"

ELSE IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC6-Slab-Semiheat”
ELSE set CONSTRUCTION = “OBC6-Slab-*XXX*”
ELSE IF FLOOR is labelled “$ perim-exposed” *//replaces underground wall construction with baseline construction, after choosing between two underground wall constructions, exposed and regular*
IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC6-BGWalls-Semiheat-Exp”
ELSE set CONSTRUCTION = “OBC6-BGWalls-*XXX*-Exp”
ELSE IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC6-BGWalls-Semiheat”
ELSE set CONSTRUCTION = “OBC6-BGWalls-*XXX*”
Review all DOOR *//replaces door construction with baseline construction*
IF SPACE is labelled “$ Semiheated”, set CONSTRUCTION = “OBC6-Door-Semiheat”
ELSE set CONSTRUCTION = “OBC6-Door-*XXX*”

Fenestration
Find “Building Type” in **Envelope Calculations: Building Type Table** *//inserts fenestration inputs based on building type*
IF “**Baseline” heading** value = Nonresidential, insert all inputs under “**Nonresidential” heading** in **Envelope -Fenestration: OBC SB-10 Climate Zone 6 Table**
Define string *XXX* = “Nonres”
ELSE insert all inputs under “**Residential” heading** in **Envelope -Fenestration: OBC SB-10 Climate Zone 6 Table**
Define string *XXX* = “Res”
Insert all inputs under **“Semiheated” heading** in **Envelope -Fenestration: OBC SB-10 Climate Zone 6 Table**
Review all WINDOW
IF EXTERIOR-WALL: LOCATION = TOP *//replaces skylight glass-type with baseline glass-type*
IF SPACE is labelled “$ Semiheated”, set GLASS-TYPE = “OBC6-Skylight-Semiheat”
ELSE set GLASS-TYPE = “OBC6-Skylight-*XXX*”
ELSE IF SPACE is labelled “$ Semiheated”, set GLASS-TYPE = “OBC6-Window-Semiheat” *//replaces window glass-type with baseline glass-type*
ELSE set GLASS-TYPE = “OBC6-Window-*XXX*”

From this point onward, the OBC process directly matches the ASHRAE Process, beginning from the **“*Lighting*” heading** on page B-7 of **Appendix B – ASHRAE Baseline Decision-making Process**, substituting “OBC-Baseline.inp” for “Baseline.inp”.

References

2030 Districts. 2016. *Toronto 2030 District.* 2030 Districts. Accessed May 8, 2016. http://www.2030districts.org/toronto/about.

Allegrini, J., K. Orehounig, G. Mavromatidis, F. Ruesch, V. Dorer, and R. Evins. 2015. "A review of modelling approaches and tools for the simulation of district-scale energy systems." *Renewable and Sustainable Energy Reviews* 52: 1391-1404. doi:10.1016/j.rser.2015.07.123.

ALwaer, H., and D.J. Clements-Croome. 2010. "Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings." *Building and Environment* 45: 799-807.

Architecture 2030. 2014. "Roadmap to Zero Emissions: Submission to the Ad Hoc Working Group on the Durban Platform for Enhanced Action." June 4. Accessed May 2, 2016. http://architecture2030.org/initiatives/roadmap-to-zero/.

—. 2015. *The 2030 Challenge.* Architecture 2030. Accessed June 10, 2016. http://architecture2030.org/2030_challenges/2030-challenge/.

—. 2007. "The 2030 Challenge Benchmark Set." May 4. Accessed May 3, 2016. http://architecture2030.org/files/Press_Release_5_4_07.pdf.

—. n.d. "U.S. and Canadian Target Tables: Canadian Commercial Regional Averages." Accessed May 5, 2016. http://architecture2030.org/files/2030_Challenge_Targets_Com_Canada.pdf.

—. n.d. "U.S. and Canadian Target Tables: U.S. National Medians." Accessed May 5, 2016. www.architecture2030.org/files/2030_Challenge_Targets_National.pdf.

Ascione, F., R.F. Masi, F. De Rossi, R. Fistola, M. Sasso, and G.P. Vanoli. 2013. "Analysis and diagnosis of the energy performance of buildings and districts: Methodology, validation and development of Urban Energy Maps." *Cities* (35): 270-283. doi:10.1016/j.cities.2013.04.012.

ASHRAE. 2010. *ANSI/ASHRAE/IES Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings.* American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE).

Attia, S., E. Gratia, A. De Herde, and J.L.M. Hensen. 2012. "Simulation-based decision support tool for early stages of zero-energy building design." *Energy and Buildings* (49): 2-15. doi:10.1016/j.enbuild.2012.01.028.

Babaei, T., H. Abdi, C.P. Lim, and S. Nahavandi. 2015. "A study and a directory of energy consumption data sets of buildings." *Energy and Buildings* (94): 91-99. doi:10.1016/j.enbuild.2015.02.043.

Barley, D., M. Deru, S. Pless, and P. Torcellini. 2005. *Procedure for Measuring and Reporting Commercial Building Energy Performance.* Golden: National Renewable Energy Laboratory (NREL).

Boston Redevelopment Authority Planning Division. 2015. *Boston Community Energy Study: Exploring the potential for energy generation, district energy, and microgrids.* Boston: Boston Redevelopment Authority.

CaGBC. n.d. *LEED Project Profiles.* Canada Green Building Council. Accessed July 15, 2016. http://leed.cagbc.org/LEED/projectprofile_EN.aspx.

Chung, W. 2011. "Review of building energy-use performance benchmarking methodologies." *Applied Energy* (88): 1470-1479. doi:10.1016/j.apenergy.2010.11.022.

Crawley, D. B., J. W. Hand, M. Kummert, and B. T. Griffith. 2008. "Contrasting the capabilities of building energy performance simulation programs." *Building and Environment* 43: 661-673.

Davila, C. C., C. Reinhard, and J. Bernis. 2016. *Modeling Boston: A workflow for the generation of complete urban building energy demand models from existing urban geospatial datasets.* Cambridge, MA: Boston Redevelopment Authority.

Eichholtz, P., N. Kok, and E. Yonder. 2012. "Portfolio greenness and the financial performance of REITs." *Journal of International Money and Finance* 31 (7): 1911-1929.

Enbridge Gas. 2016. *Large Volume Rates: Rate 6 - Commercial and Industrial.* Enbridge Gas Distribution Inc. July 1. Accessed July 25, 2016. https://www.enbridgegas.com/businesses/accounts-billing/gas-rates/large-volume-rates/rate-6.aspx.

Feifer, L. 2011. "786: Sustainability Indicators in Buildings: Identifying Key Performance Indicators." *PLEA 2011.* Louvain-la-Neuve, Belgium.

Foucquier, A., S. Robert, F. Suard, L. Stephan, and A. Jay. 2013. "State of the art in building modelling and energy performances prediction: A review." *Renewable and Sustainable Energy Reviews* 23: 272-288.

Fracastoro, G.V., and M. Serraino. 2011. "A methodology for assessing the energy performance of large scale building stocks and possible applications." *Energy and Buildings* (43): 844-852. doi:10.1016/j.enbuild.2010.12.004.

Fumo, N. 2014. "A review on the basics of building energy estimation." *Renewable and Sustainable Energy Reviews* (31): 53-60.

Gould, S., and M. Hawkins. 2015. "Modelling multifamily buildings with eQuest: A case study of prediction vs. reality." *2015 ASHRAE Winter Conference - Papers* 1-8.

Gowri, K., D. Winiarski, and R. Jarnagin. 2009. *Infiltration Modelling Guidelines for Commercial Building Energy Analysis.* Springfield, VA: Pacific Northwest National Laboratory.

Haapio, A., and P. Viitaniemi. 2008. "A critical review of building environmental assessment tools." *Environmental Impact Assessment Review* (28): 469-482. doi:10.1016/j.eiar.2008.01.002.

Han, X., J. Pei, J. Liu, and L. Xu. 2013. "Multi-objective building energy consumption prediction and optimization for eco-community planning." *Energy and Buildings* (66): 22-32. doi:10.1016/j.enbuild.2013.07.016.

Hussain, S., H. A. Gabbar, F. Musharavati, and S. Pokharel. 2013. "Key Performance Indicators (KPIs) for Evaluation of Energy Conservation in Buildings." *IEEE International Conference on Smart Energy Grid Engineering.* Oshawa, ON.

IES. n.d. *VE-Gaia: ASHRAE 90.1 App-G PRM Navigator*. Glasgow: Integrated Environmental Solutions Ltd (IES).

IESO. 2016. *2015 Electricity Production, Consumption, Price and Dispatch Data.* Independent Electricity System Operator. Accessed July 25, 2016. http://www.ieso.ca/Pages/Power-Data/2015-Electricity-Production-Consumption-Price-and-Dispatch-Data.aspx.

Integral Group. 2015. *Energy Reporting & Benchmarking for Large Buildings: Policy Development Consultations: Summary Report.* Toronto: City of Toronto.

Integral Group. 2015. *Global Best Practices in Energy Efficiency Policy.* Toronto: Integral Group and City of Toronto.

IPCC. 2014. *Climate Change 2014: Synthesis Report. Contribution.* Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)], Geneva, Switzerland: Intergovernmental Panell on Climate Change (IPCC).

Kavgic, M., A. Magrogianni, D. Mumovic, A. Summerfield, Z. Stevanovic, and M. Djurovic-Petrovic. 2010. "A review of bottom-up building stock models for energy consumption in the residential sector." *Building and Environment* (45): 1683-1897.

Kesik, Ted. 2015. *Vital Signs: Towards Meaningful Building Performance Indicators.* Toronto: University of Toronto.

Kinney, S., and M.A. Piette. 2002. "Development of a California Commercial Building Energy Benchmarking Database." In *2002 ACEEE Summer Study on Energy Efficiency in Buildings*, 109-120. Washington, DC: American Council for an Energy Efficient Economy (ACEEE).

Kok, N., M. McGraw, and J.M. Quigley. 2011. "The Diffusion of Energy Efficiency in Building." *The American Economic Review 101 (3), Papers and proceedings of the one hundred twenty third annual meeting of the American Economic Association.* 7.

Lawrence Berkeley National Laboratory. 2016. *DOE-2.3: Building Energy Use and Cost Analysis Program.* Camarillo, CA: James J. Hirsch & Associates.

Lee, W.M., and J Burnett. 2008. "Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED." *Building and Environment* 43: 1882-1891.

Livegreen Toronto. 2015. *Toronto Green Standard: Version 2.0 for New Mid to High-Rise Residential and All Non-Residential Development.* Toronto: City of Toronto.

Long, M. 2014. *USGBC Announces Extension of LEED 2009.* U.S. Green Building Council. November 18. Accessed July 15, 2016. http://www.usgbc.org/articles/usgbc-announces-extension-leed-2009.

MECC. 2016. *Canada's Second Biennial Report on Climate Change.* Gatineau, QC: Ministry of Environment and Climate Change Canada, Government of Canada.

Ministry of Municipal Affairs and Housing. 2012. "Building Code Act, 1992: Supplementary Standard SB-10 - Energy Efficiency Supplement."

—. 2012. "Ontario Regulation 322/12 (Building Code Act 1992)."

Mwasha, A., R. G, Williams, and J. Iwaro. 2011. "Modeling the performance of residential building envelope: The role of sustainable energy performance indicators." *Energy and Buildings* 43: 2108-2117.

NRCan. 2008. *EE4 Software Version 1.7: Modelling Guide.* Ottawa: Natural Resources Canada (NRCan).

NRCan. 2015. *Energy Fact Book: 2015-2016.* Ottawa: Natural Resources Canada (NRCan), Government of Canada.

NRCan. 2016. *Energy Use Data Handbook: 1990 - 2013.* Ottawa: Natural Resources Canada (NRCan).

NRCan. 2016. *Release Notes for CAN-QUEST NECB v1.1.* Ottawa: Natural Resources Canada (NRCan).

Omrany, H., and A. K. Marsono. 2016. "Optimization of Building Energy Performance through Passive Design Strategies." *British Journal of Applied Science & Technology* 13 (6): 1-16.

Pacheco, R., J. Ordonez, and G. Martinez. 2012. "Energy efficient design of building: A review." *Renewable and Sustainable Energy Reviews* 16: 3559-3573.

Perez-Lombard, L., J. Ortiz, R. Gonzales, and I.R. Maestre. 2009. "A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes." *Energy and Buildings* (41): 272-278. doi:10.1016/j.enbuild.2008.10.004.

Reinhart, C.F., and C.C. Davila. 2016. "Urban building energy modelling - A review of a nascent field." *Building and Environment* (97): 196-202. doi:10.1016/j.buildenv.2015.12.001.

REMI Network. 2015. "Setting Benchmarks in Toronto's 2030 District." April 16. Accessed June 5, 2016. https://www.reminetwork.com/articles/setting-benchmarks-in-torontos-2030-district/.

Rodriguez-Ubinas, E., C. Montero, M. Porteros, S. Vega, I. Navarro, M. Castillo-Cagigal, E. Matallanas, and A. Gutierrez. 2014. "Passive design strategies and performance of Net Energy Plus Houses." *Energy and Buildings* 83: 10-22.

Rosenberg, M., and C. Eley. 2013. "A Stable Whole Building Performance Method for Standard 90.1." *ASHRAE Journal* 33-45.

Save On Energy. 2016. *High Performance New Construction.* Independent Electricity System Operator. Accessed June 20, 2016. https://saveonenergy.ca/Business/Program-Overviews/New-Construction.aspx.

Su, B. 2011. "The impact of passive design factors on house energy efficiency." *Architectural Science Review* 54: 270-276.

Susorova, I., M. Tabibzadeh, A. Rahman, H.L. Clack, and M. Elnimeiri. 2013. "The effect of geometry factors on fenestration energy performance and energy savings in office buildings." *Energy and Buildings* 57: 6-13.

Tardioli, G., R. Kerrigan, M. Oates, J. O'Donnell, and D. Finn. 2015. "Data driven approaches for prediction of building energy consumption at urban level." *Energy Procedia* (78): 3378-3383.

The American Institute of Architects. 2016. *2030 Design Data Exchange.* The American Institute of Architects. Accessed May 27, 2016. http://www.aia.org/practicing/AIAB107382.

TOcore Energy Working Group. 2016. *Energy Working Group Report: Phase 1 - Existing Conditions & Emerging Priorities.* Toronto: City of Toronto.

TOcore. 2016. *TOcore Planning Downtown.* City of Toronto. Accessed July 15, 2016. http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=b726a00f92dd5410VgnVCM10000071d60f89RCRD.

Toronto Hydro. 2016. *Business Electricity Rates.* Toronto Hydro Corporation. May 1. Accessed July 25, 2016. http://www.torontohydro.com/sites/electricsystem/business/rates/Pages/busrates.aspx.

U.S. Green Building Council. 2013. *LEED reference guide for building design and construction.* Washington: U.S. Green Building Council.

US EPA. n.d. *EPA's Target Finder calculator.* Accessed 05 27, 2016. https://www.energystar.gov/buildings/service-providers/design/step-step-process/evaluate-target/epa%E2%80%99s-target-finder-calculator.

Winkelmann, F. 2002. "Underground Surfaces: How to get a better underground surface heat transfer calculation in DOE2.1E." *Building Energy Simulation User News* 23 (6): 5-14.

Zhao, H., and F. Magoules. 2012. "A review on the prediction of building enegy consumption." *Renewable and Sustainable Energy Reviews* (16): 3586-3592.