Development of Canadian Building Archetypes in TRNSYS for NZEB Analysis

CCTC 2013 Paper Number 1569694757
J. Tamasauskas[1], M. Kegel[1] and R. Sunye[1]
[1] Natural Resources Canada, CanmetENERGY, Varennes, Canada

Abstract

This paper presents the development of a Canadian building archetype library using the TRNSYS energy simulation program. The objective of the described work is to create a set of reference buildings for the analysis of high efficiency heating and cooling systems. A total of two building types are selected and developed for five distinct climate regions and two construction vintages. For each building type, the building geometry, envelope, and reference mechanical system is described. A summary of key energy performance results is then presented, along with a discussion of future work.

Keywords: NZEB, commercial buildings, energy modeling, TRNSYS

Résumé

Cet article présente la construction d’une bibliothèque canadienne archetype à l’aide du programme de simulation énergétique TRNSYS. Les travaux décrits ont pour objectif la création d’un ensemble de bâtiments types de référence aux fins de l’analyse de systèmes de chauffage et de climatisation à haute efficacité. Deux types de bâtiments ont été choisis et modélisés pour cinq régions aux climats distincts et pour deux époques de construction. Pour chaque type de bâtiment, l’article décrit la géométrie du bâtiment, son enveloppe et le système mécanique de référence. Il présente un sommaire des résultats les plus significatifs en matière de rendement énergétique, ainsi que les travaux qui s’ensuivront.

Mots-clés : NZEB, édifices commerciaux, modélisation énergétique, TRNSYS

1. Introduction

Increasing concern about global warming and greenhouse gas emissions has led to a strong interest in reducing energy use. Buildings are major consumers of energy, accounting for 30% of global energy consumption [1]. In Canada, commercial and institutional buildings account for 12% of all secondary energy use, with 59% of this total directed towards space heating, space cooling, and DHW [2]. Thus, promoting energy efficiency within the building sector can have a significant impact on overall energy use, both on a national and global scale.

1.1 Net zero energy buildings

The recognition of buildings as major consumers of energy has provided motivation for the development of new standards and targets for building energy performance. One of the most widely discussed concepts for future construction is the Net Zero Energy Building (NZEB), which can be defined as a building that produces as much energy as it consumes on an annual basis through the use of onsite renewable generation [3]. Achieving a NZEB requires a careful balance between the implementation of energy conservation measures, and the addition of renewable power generation capacity. In general, building loads must be at a low level before the integration of onsite power generation becomes cost effective [4]. Two distinct pathways can be used to achieve the necessary load reductions:

I. A super efficient building envelope, or;
II. A well insulated building envelope in combination with a high efficiency mechanical system (e.g a heat pump)

Although the first approach is common when designing high performance buildings, a number of drawbacks still exist. These include high initial costs, and a loss of usable floor space because of thicker walls. Furthermore, this approach is often unfeasible in existing buildings due to the location of installed equipment, and the impact that the renovations would have on the building tenants. As such, the integration of a high efficiency mechanical system is appealing within the context of NZEBs. Heat pumps are particularly attractive options for these applications since they are capable to delivering more energy than they consume by upgrading the free energy available from renewable sources.

1.2 Commercial building archetypes

In order to assess and compare different heating and cooling technologies it is important to have a common reference model. This model should provide a representative description of the building geometry, envelope, and mechanical system based on the building type and climate region. The concept of reference buildings for energy modeling has been examined previously. In 2007, the US Department of Energy (DOE) created a series of building archetypes for the EnergyPlus simulation program [5]. A total of 16 building types were developed for 16 American cities, with all envelope and mechanical systems selected to represent typical construction practices. This work served as a base for a series of Canadian archetypes developed for the DOE 2.1E simulation program [6]. While both archetype libraries provided detailed descriptions of common building types in their respective regions, the energy modeling tools used were not well suited to the simulation of complex mechanical systems often found in NZEBs. As such, there was a need to develop a new set of Canadian commercial building archetypes within a more flexible simulation environment in order to analyze the impact that innovative mechanical systems have on high performance building design.

1.3 Archetype Development in TRNSYS

The developed archetype library is intended to serve as a base for the examination of renewable energy systems within NZEBs. These systems include heat pump, cogeneration, and solar thermal technologies. As such, the new archetype library needed to be developed within a simulation environment that facilitated the accurate and efficient assessment of these technologies. The TRNSYS energy simulation program [7] has been recognized as a leading tool for the simulation of these complex technological integrations [8], and was therefore selected as the simulation software for model development. TRNSYS represents a highly flexible design environment with a large library of components for modeling solar and heat pump systems. The software also allows users to easily add new components should existing models prove inadequate.

1.4 Project scope

A new series of Canadian building archetypes was developed as part of a larger project focusing on the integration of high efficiency heat pump and renewable energy systems into commercial buildings. The current library consists of 20 archetypes, comprising two building types, five Canadian regions, and two construction vintages. This library will be expanded in the future to include additional building types and climate zones in Canada.

A large office and a multi-unit residential building (MURB) were selected as the two initial building types. Both building types were selected due to their prevalence within the building stock, and the unique challenges that they pose regarding the implementation of high efficiency mechanical systems. The MURB holds particular interest as previous simulation studies have identified single family Canadian homes as prime targets for high efficiency heat pump and cogeneration systems [9,10]. The development of the MURB archetype will enable further research to determine if the results obtained are scalable to a larger building following a similar load profile.

In addition to the two building types, a total of five Canadian cities have been examined to date: Montreal, Toronto, Calgary, Vancouver, and Yellowknife. Each region was selected for its distinct climate and regional construction requirements. In order to assess the impact of new and existing buildings, each combination of building type and location was also modeled according to both the NECB 2011 [11] and MNECB 1997 [12] minimum requirements.

1.5 Objectives

The objective of this paper is to outline the development of new Canadian commercial building archetypes in TRNSYS. These archetypes are to be used as part of a larger project examining the role of high efficiency mechanical systems in NZEB design. The development of each building archetype is described through a presentation of the selected building geometry, envelope, and mechanical system. Key energy performance results are provided to define the current state of the building and identify major end uses. Finally, each archetype is placed in the context of the larger project through a discussion of future work.

2. Model development

This section presents the development of the large office and MURB building models. For each building type, an energy model was created using the multi-zone building component (Type 56a) in TRNSYS v. 17. All required heating, cooling, ventilation, and control systems were modelled using available components from the TRNSYS library.

All internal loads, DHW requirements, and operating schedules were based on information provided in the MNECB 1997 and NECB 2011 for the appropriate building type and construction vintage.

This paper focuses on model development according to the NECB 2011 in order to provide a baseline for new building construction.

2.1 Large office energy model

Development of the large office model can be divided into a definition of the building geometry, envelope, and mechanical systems.

2.1.1 Building geometry

The building geometry used for the large office was obtained from the available DOE EnergyPlus model [13]. Although this model was developed to represent the U.S building stock, it was assumed that the defined geometry was also applicable to Canada due to the similarities in design and construction practises between the two countries. It should be noted that a smaller office model was developed for the Yellowknife region, as the DOE archetype is not representative of the buildings in this area.

Table 1 provides a general description of the selected building geometry. All geometry parameters defined in the table remained constant for each region and construction vintage examined.

Table 1: Summary of building geometry for large office

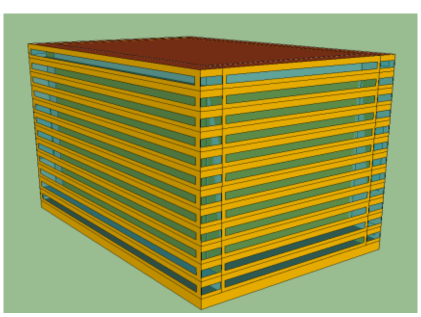
Total Floors	13 (incl. basement level)
Total Floor Area	46318 m^2
Aspect Ratio	1.5
Floor-Floor Height	3.96 m
Orientation	Due South

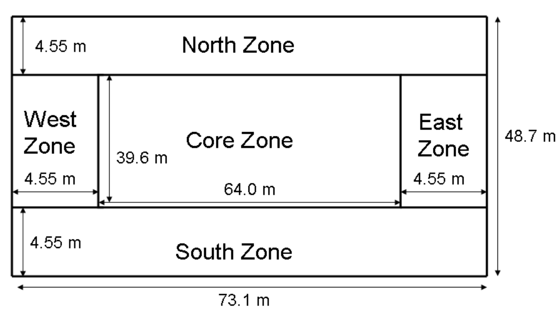
Window glazing percentages were a function of the location and the construction vintage.

The above defined geometry was used to develop a three dimensional building model using the TRNSYS 3D plugin (Figure 1(a)). Appropriate zoning of the building was vital due to the diversity of heating and cooling loads between the perimeter and core sections of the building. The developed energy model needed to have enough thermal zones to properly describe building performance, while at the same time avoiding excess zoning that would increase the simulation time. To balance these two objectives, the building was divided into four sections:

i. Basement
ii. First floor
iii. Mid-floor, which represented the ten middle floors of the building
iv. Top floor

The basement section was modelled as a single zone because of the lack of fenestration, and the consistent boundary temperature for each of the five exterior surfaces. Each above ground building section was divided into five zones in order to account for the diversity of loads caused by incident solar radiation (Figure 1(b)).





(a) (b)

Figure 1 (a). Three dimensional large office model
(b). Thermal zoning of large office building

2.1.2 Building envelope

Building envelope performance was based on the minimum requirements specified in the NECB 2011. Care was taken to ensure that the specified envelope constructions were consistent with current practises. A basic description of each envelope component is provided in Table 2. As an example, required thermal performance is provided for NECB Zone 6 (includes Montreal).

Table 2: Building envelope constructions for large office

Component	Construction Type	Thermal Performance (W/m^2K) [11]
Above Ground Walls	Insulated Mass Wall	0.247
Below Grade Walls	Insulated Concrete Wall	0.284
Roof	Metal Deck + Insulation	0.183
Slab	Insulated Concrete Slab	0.757 (for 1.2m)

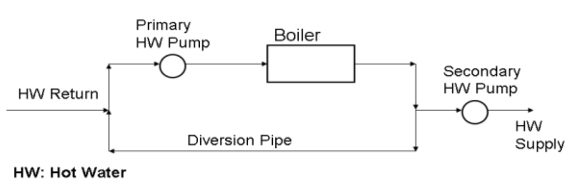
2.1.3 Mechanical systems

Mechanical systems for the large office were based on information provided in the NECB 2011. The selected system design consisted of:

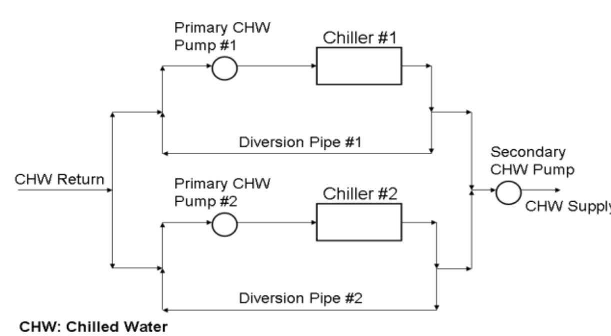
i. A VAV air distribution system
ii. A water cooled chiller with a cooling tower
iii. Baseboard heaters with a fuel fired boiler

Each of the four building sections was served by a dedicated air handling unit. This unit supplied air to each thermal zone at a constant temperature of 13°C. The airflow to each zone was varied between defined minimum and maximum values based on a demand for cooling.

The proposed heating and cooling system layouts are shown below (Figure 2(a) and Figure 2(b), respectively). Each system used a primary/secondary piping network to provide constant flow to the boiler or chillers while varying the flow to the terminal equipment. This design significantly reduced the pumping energy needed to circulate flow to the coils and terminal units, while still maintaining the required constant flow conditions through the primary equipment.



(a)



(b)

Figure 2(a). Heating system for large office
(b). Cooling system for large office

All mechanical systems were sized using the calculated building loads and the procedures defined in the NECB 2011. Pumping power requirements were based on values found in ASHRAE 90.1 Appendix G [14].

2.2 MURB energy model

Development of the MURB energy model was also divided into a description of the building geometry, envelope, and mechanical systems.

2.2.1 Building geometry

The building footprint for the MURB was obtained using the available DOE EnergyPlus model [13]. A summary of key building parameters is provided in Table 3. All listed parameters remained constant regardless of the region and construction vintage.

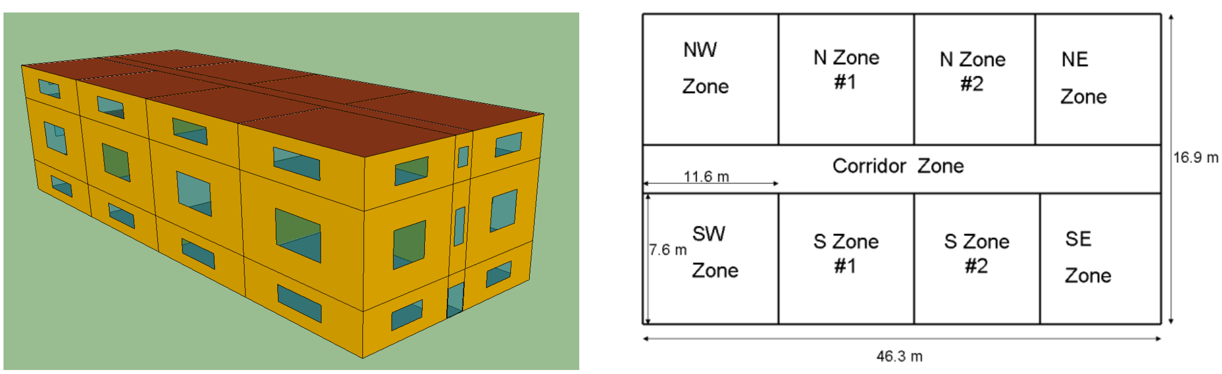
Table 3: Building geometry for MURB

Total Floors	4 (all above ground)
Total Floor Area	3135 m^2
Aspect Ratio	2.7
Floor-Floor Height	3.05 m
Orientation	Due South
Window to Wall Ratio	15%

Thermal zoning was an important consideration when developing the model (Figure 3(a)). Similar to the office archetype, the MURB was divided vertically into three sections:

i. Ground Floor
ii. Middle Floors (typical of two floors)
iii. Top Floor

Each building section was then divided into nine thermal zones as shown in Figure 3(b). The selected zoning scheme allowed the energy model to account for differences in thermal loads due to fenestration and solar irradiation, and to determine energy use profiles for each apartment. All eight identical larger zones on each floor were assumed to be used as apartments, with the exception of one unit on the ground floor that was used as a rental office.



(a) (b)

Figure 3. (a) Three dimensional MURB model
(b) Thermal zoning of MURB

2.2.2 Building envelope

Insulation levels for each envelope component were determined using the minimum requirements in the NECB 2011. A brief description of the construction used for each envelope component is provided in Table 4. Required thermal performance is provided for NECB Zone 7A (Calgary).

Table 4: Building envelope constructions for MURB

Component	**Construction Type**	**Thermal Performance (W/m^2K) [11]**
Walls	Insulated Steel Frame	0.210
Roof	Built Up Roof + Insulation	0.162
Slab	Insulated Concrete Slab	0.757 (for 1.2 m)

2.2.3 Mechanical systems

The mechanical system in the MURB archetype was developed using information from the NECB 2011, and consisted of:

i. A forced air system with a hot water coil for each apartment
ii. A central hot water boiler
iii. A direct expansion (DX) split cooling system for each apartment

The proposed mechanical system represented a distributed approach to heating and cooling, allowing each apartment to meet its own individual loads. Each apartment was equipped with its own forced air system, which consisted of a fan, a heating coil, and a DX cooling coil if space cooling is required. Fresh air from the outdoors is drawn through the forced air system, with a heat recovery system (ie an HRV) implemented depending on the climate region as defined by the NECB 2011. The blower of the forced system is assumed to be 2-speed, operating on high speed for any heating or cooling demand, or continuously on low speed to circulate the fresh air throughout the apartment. To ensure comfort levels are maintained during the winter, each system is also equipped with a humidification unit.

All heating loads were met using a hot water coil inside the forced air system. Cooling was achieved using a split system, with an outdoor unit supplying the refrigerant to air heat exchanger in the supply duct. Each corridor was also equipped with an air handling unit with a heating coil. No cooling system was implemented in these zones.

3. Archetype energy performance

One of the primary reasons for developing archetypes was to gain an understanding of the energy performance of each building type. As such, TRNSYS was used to perform an annual simulation of each energy model using the appropriate weather file for the region. A 7.5 minute time step was selected for each simulation in order to properly model equipment controls while still maintaining a reasonable simulation time.

Key energy performance results are presented for each building type and one Canadian region. Findings are provided only for the NECB 2011 vintage in order to investigate the performance of new constructions.

3.1 Large office archetype

Results for the large office are presented for the Montreal region. Figure 4 shows the peak heating and cooling loads for a typical floor in the building. Heating loads have been divided into envelope and ventilation subsections to show the additional load imposed by the continuous supply of 13°C ventilation air.

Thermal loads vary greatly between each zone, demonstrating the potential for using distributed mechanical systems which can be tailored to meet the individual demands of each area. The large core heating and cooling loads are primarily a function of zone size: The core zone accounts for 71% of the floor area.

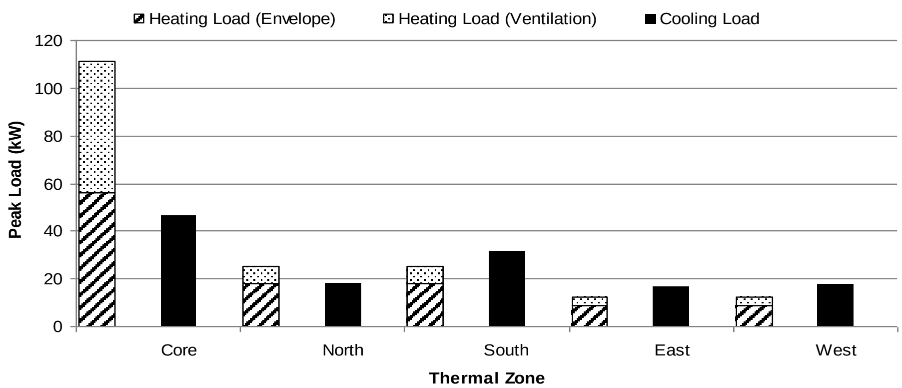


Figure 4. Peak thermal loads for large office

Figure 5 shows the total monthly energy use of the building. The energy use profile lends credibility to the developed energy model, with a clear increase in building energy use during the winter months when heating loads are higher. The total normalized annual energy use of the building was calculated to be 164.1 kWh/m², which corresponds well with available data for new large office constructions in North America [13].

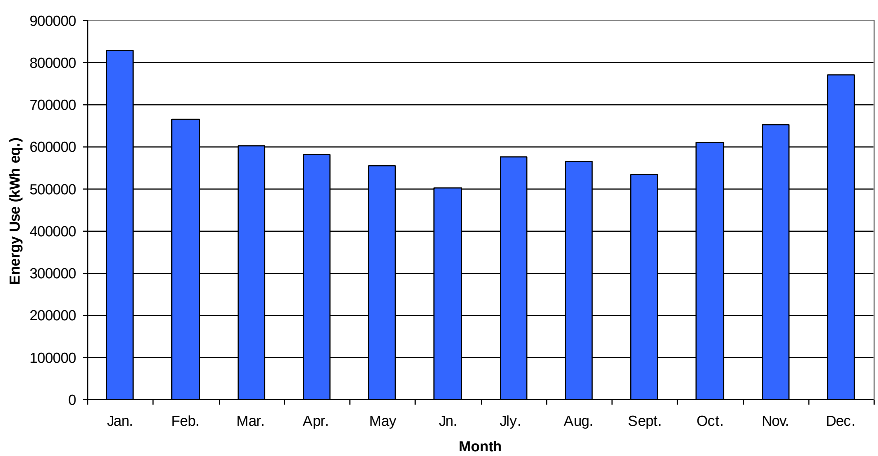


Figure 5. Total monthly energy use for large office

Figure 6 shows the distribution of annual energy use. The cold Montreal climate results in a heating dominated building, with space heating accounting for over 30% of annual energy use. Cooling appears to play a much smaller role in total energy use, primarily due to the colder climate and increased efficiency of the chillers in comparison to the gas fired boilers.

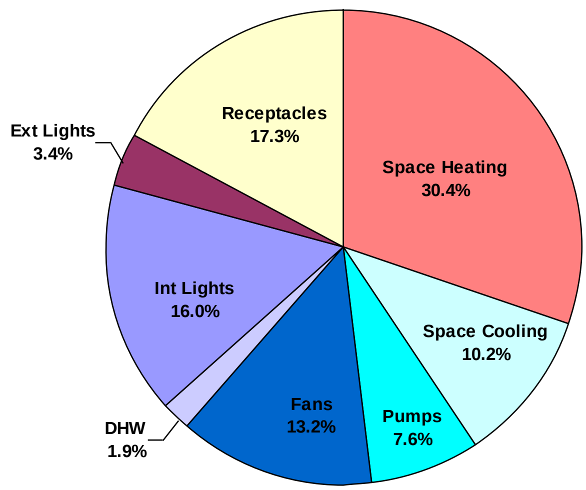


Figure 6. Distribution of annual energy use for large office

3.2 MURB archetype

Results for the MURB archetype are presented for Calgary. Figure 7 shows the total building energy use by month. The energy model confirms initial expectations of a heating dominated building, with total energy use peaking during the colder winter months. The annual energy use intensity was calculated to be 209.9 kWh/m², which corresponds well with similar newly built MURBs in North America [5].

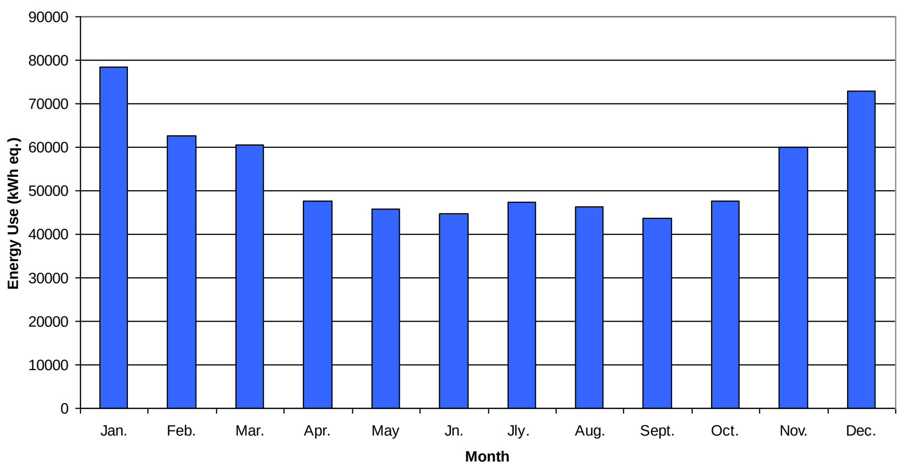


Figure 7. Total monthly energy use for MURB

Figure 8 shows the distribution of annual energy use for the MURB in Calgary. A significant portion of energy use is directed towards the mechanical system, with space heating, DHW, and fan use comprising nearly 60% of the total energy consumption of the building. The results confirm the heating dominated nature of the Calgary climate, while also highlighting the significance of the DHW load in this type of residential building (18% of energy use).

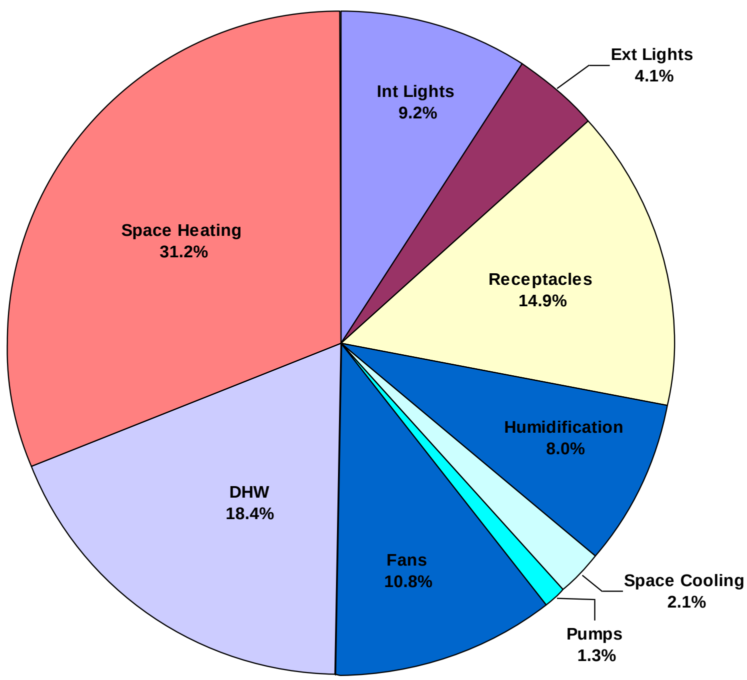


Figure 8. Energy use distribution for MURB

3.3 Comparison of building archetype performance

A comparison of the energy use distributions for both building types reveals important information regarding system design. The largest end-uses for the MURB are tied to the operation of the mechanical system (space heating, DHW, fans), while many of the primary loads in the large office are related to the electrical system (lighting, receptacles). This is particularly important for NZEB design, as it shapes the type of system that should be implemented. For the large office, any mechanical system should focus on meeting the space heating loads as efficiently as possible. MURB mechanical systems should serve the dual purpose of providing space heating while meeting at least a portion of the DHW load in a highly efficient manner.

4. Future work

The overall objective of this research is to identify the ideal heating and cooling systems for each building type by region and construction vintage. In particular, heat pump systems have been identified as important components in future NZEB design [3]. The archetype models developed within this paper act as the necessary platform for the development, analysis, and comparison of these systems.

Several heat pump systems will be examined to identify the most efficient and cost effective implementations. These range from ground source and cold climate air-source heat pump systems to more complex integrations of heat pump units with solar thermal technologies. Promising results have already been obtained for certain solar heat pump layouts in the residential sector [15]. The archetypes will afford the opportunity to examine these systems within a larger context.

Each heat pump integration will be examined within the framework of a systematic techno-economic analysis methodology. This will include an analysis both of the operating costs, and the associated equipment, labour and maintenance costs of each option. In the case of more complex combinations of heat pumps and solar technologies, optimization techniques will be used to identify the most cost effective equipment sizing.

5. Conclusions

A series of Canadian commercial building archetypes was developed for the TRNSYS energy simulation program. The developed archetype library was composed of two building types (Large office, multi-unit residential) examined in five Canadian climate regions. Two construction vintages were also applied to represent new and existing buildings.

For each archetype, an energy model was created in TRNSYS. This energy model contained a detailed description of the building geometry, envelope, mechanical system, and operational parameters based on the building type, region, and construction vintage. Each energy model was simulated on an annual basis to provide a description of building energy performance.

The primary purpose for archetype development was to provide a base for the examination of high efficiency mechanical systems in NZEBs. As such, future work is planned to investigate the integration of several innovative heat pump systems into each archetype. A systematic techno-economic analysis methodology will also be applied in order to determine the most cost effective integration by region and building type.

6. Acknowledgements

The authors wish to thank Mr. Stephen Pope for his valuable insights into archetype development, and for providing access to developed EE4 Canadian archetypes. The authors also acknowledge the financial support received from NRCan for this project.

7. References

[1] International Energy Agency (IEA), “Energy efficiency”, Available at: http://www.iea.org/ [Accessed January 2013]

[2] Office of Energy Efficiency (OEE), “Energy efficiency trends in Canada 1990 to 2007”, NRCan, Ottawa, 2010

[3] IEA Heat Pump Centre, “The role of heat pumps in net zero energy buildings”, *IEA Heat Pump Centre Newsletter*, Vol. 30, Iss. 3, 2012, pp. 3

[4] Sartori I., Napolitano A., Voss K., "Net zero energy buildings: A consistent definition framework", *Energy and Buildings*, Vol. 48, May, 2012, pp. 220-232

[5] Torcellini P., Deru M., Griffith B., Benne K., Halverson M., Winiarski D., Crawley D.B., "DOE commercial building benchmark models", Proceedings of 2008 ACEEE Summer Study on Energy Efficiency in Buildings, August, 2008

[6] Pope S., Personal email communications, January, 2013

[7] Klein S. A., et al., "TRNSYS 17 – A TRaNsient SYstem Simulation program, user manual", University of Wisconsin-Madison, Solar Energy Laboratory, Madison, USA, 2010

[8] Crawley D., Hand J., Kummert M., Griffith B., "Contrasting the capabilities of building energy performance simulation programs", Available at: http://gundog.lbl.gov/dirpubs/2005/05_compare.pdf [Accessed February 2013]

[9] Kegel M., Sunye R., Tamasauskas J., "Life cycle cost comparison and optimization of different heat pump systems in the Canadian climate", Proceeedings of eSim 2012, May, 2012

[10] Kegel M., Sunye R., Galanis N., Douglas M., "Assessment of a sorption chiller driven by a cogeneration unit in a residential building", Proceedings of the International Sorption Heat Pump Conference, April, 2011

[11] Canadian Commission on Building and Fire Codes, "National Energy Code of Canada for Buildings (NECB) 2011", National Research Council of Canada, Ottawa, 2011

[12] Canadian Commission on Building and Fire Codes, "Model National Energy Code of Canada for Buildings (MNECB) 1997", National Research Council of Canada, Ottawa, 1997

[13] U.S Department of Energy (DOE), "Commercial Reference Buildings", Available at: http://www1.eere.energy.gov/buildings/commercial/ref_buildings.html [Accessed January 2013]

[14] ASHRAE, "ASHRAE standard 90.1-2010: Energy standard for buildings except low-rise residential buildings", ASHRAE, Atlanta, 2010

[15] Tamasauskas J., Poirier M., Zmeureanu R., Sunye R., "Modeling and optimization of a solar assisted heat pump using ice slurry as a latent storage material", *Solar Energy*, Vol. 86, Iss. 11, 2012, pp. 3316-3325

8. Biography

Justin Tamasauskas and Martin Kegel are research officers at the CanmetENERGY technology center in Varennes. Both specialize in energy simulation and building energy analysis projects. Roberto Sunye is a senior project manager at CanmetENERGY-Varennes. His work focuses on the development and integration of heat pump technologies in the Canadian marketplace.