

DEVELOPMENT OF A FUNCTIONALITY GENERATING SIMULATIONS OF COMMERCIAL AND INSTITUTIONAL BUILDINGS HAVING REPRESENTATIVE CHARACTERISTICS OF A REAL ESTATE STOCK IN QUÉBEC (CANADA)

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ABSTRACT

This article describes the development of a functionality generating simulations of commercial and institutional buildings with representative characteristics of a real estate stock in Québec. The functionality requires very little information such as the main building activity, the floor area and the construction year of the building. With these inputs, the physical and operational characteristics (R-value of the envelope, type of windows, type of HVAC, system controls, schedules, type of activities, etc.) are statistically extracted from a database and transmitted to the input fields of an hourly building energy simulation software. It is then possible, with very little information, to simulate the energy performance of a group of buildings as seen in Québec's building stock.

INTRODUCTION

Over the last few years, Hydro-Quebec, a public utility located in Quebec (Canada), has established energy efficiency programs for buildings in order to meet high energy savings objectives. To support these programs, energy simulation tools for commercial and institutional buildings have been developed.

This paper presents the development of a functionality allowing simulations of archetype buildings, which are defined as buildings having characteristics similar to those of a certain group of buildings in Québec's real estate stock. The functionality generates a complete building model with representative characteristics using little information such as the main building activity, the floor area and the construction year of the building. With these inputs, the physical and operational characteristics of the building (aspect ratio, envelope R-value, type of HVAC, schedules, type of activities, etc.) are statistically extracted from a database and transmitted to the input fields of an hourly building energy simulation software, currently using the DOE2.1E simulation engine. The values of the characteristics are derived from various sources, including a detailed energy study of more than 14 000 buildings. This important data source made it possible to establish a distribution of values for

several key characteristics, allowing a Monte Carlo simulation analysis.

The functionality was developed for different purposes. First, it helps building modelers to rapidly create a detailed representative energy simulation model with little information. Developing detailed models is time consuming and it can be difficult to get all inputs needed. Also, the functionality generates simulations of a large group of buildings in order to represent a building stock. This could eventually be used for research on the implementation of new technologies or to evaluate the global impact of an energy efficiency measure on Québec's building stock.

Representing a building stock is quite difficult because of the diversity and the limited data on existing buildings. The structure of the functionality allows the generation of a wide range of buildings all having statistically probable characteristics. This allows the building stock diversity to be represented, and configurations that are the most suitable for efficiency measures implementation to be targeted.

The method habitually used to represent a building stock is to define typical buildings in different activity sectors and to attribute them a weighting factor in order to represent the total population. Each typical building has characteristics that are the most representative of each activity sector. The DOE Commercial Building Benchmark Models (Torricelli et al. 2008) is a good example, where 15 benchmark buildings that represent most of the commercial building stock in the U.S. were recently developed. This method leads to precise benchmark models, but does not account for the diversity of building in each activity sectors.

The following sections present the detailed approach used to generate these archetype building models and provide the data sources that were used to evaluate the building characteristics. A verification of the representative buildings generated by the functionality was also conducted by comparing the real consumption of 1 394 audited office buildings with the results of the archetype building simulations.

APPROACH

The archetype building functionality is based on the development of a software interface, the determination of the parameters values of Québec's real estate stock and the definition of rules to generate all data required for the building simulation. The general process is as follows.

At the onset, generating an archetype building model requires identifying the following five independent variables:

- Main building activity (Offices, Education, Retail,...)
- Floor area
- Construction year
- Location
- Main heating source (electricity, oil or gas)

Based on these five independent variables, a multitude of parameters that are specific to the building are extracted from a database. Then, based on several rules, the building is defined in the form of input data of an hourly building simulation software, called SIMEB (Millette et al. 2008). This software, developed by Hydro-Québec, is an interface to DOE2.1 simulation engine and eventually to EnergyPlus.

Figure 1 illustrates the process. A wizard-type user interface inputs the five independent variables mentioned above on the first tab. The four other tabs of the wizard propose some parameters value related to the building's form, the functional space areas and HVAC system types.

Once the interface is closed, the input data in the SIMEB software is automatically filled by a generator using the archetype database. At any tabs, the building could be generated once all five independent variables are identified in the first tab.

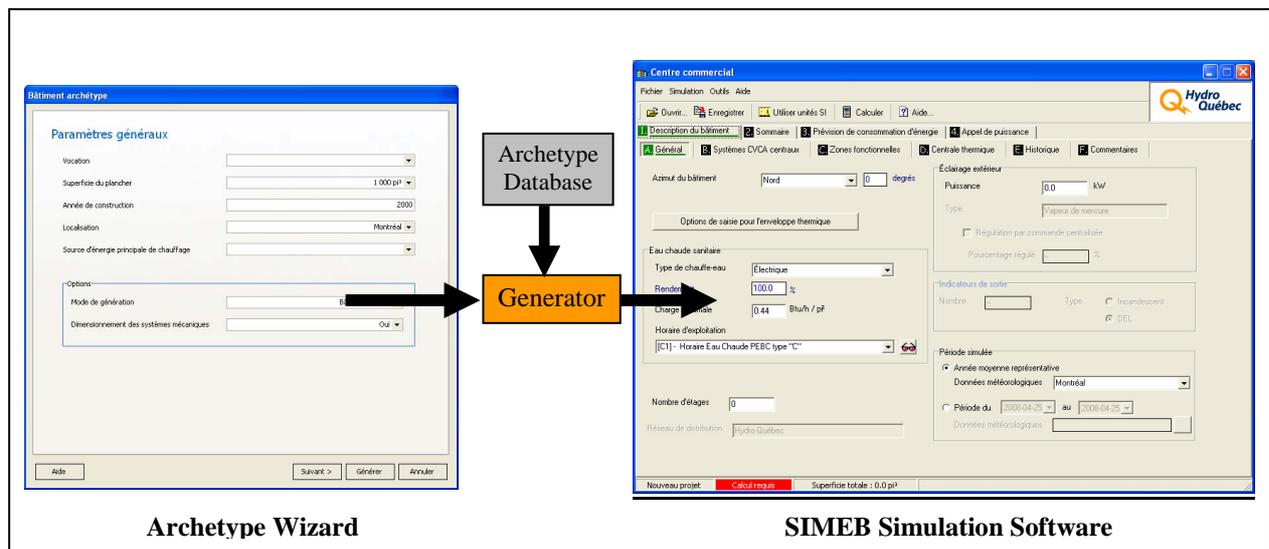
The generation of a building can be done on two modes: a "Single Building" mode or a "Building Stock" mode. The mode chosen dictates how values of the archetype database parameters are assigned.

"Single Building" mode: This mode is essentially used in the analysis of a building that is the most probable of a group of buildings. The value of a parameter is based on its highest probability. For example, if the information in the database reveals that 10% of the office buildings built since 1995 are equipped with CO₂ sensors and 90% of them are not, the value assigned by the database will dictate an absence of CO₂ sensors.

"Building Stock" mode: With this mode, a macroscopic analysis can be conducted through simulations on a significant number of buildings. It randomly attributes a parameter value based on its distribution. For example, if the information in the database stipulates that 25% of the schools in the building stock do night setback heating temperature and that 75% do not, there will be a 25% probability that building temperature schedules include night setback.

An automated process was implemented to perform batch runs of simulations in the "Building Stock" mode. As a result, it is possible to generate several different buildings with probable characteristics with the same group of independent variables (Floor area, Location, etc.)

Figure 1: Archetype generation process



ARCHETYPE DATABASE STRUCTURE

The archetype database includes the values of over 70 parameters that are specific to the building description. These parameters characterize the building based on its architecture, equipment and operations. Table 1 lists some of these parameters.

Table 1: List of Parameters

Categories	Parameters
Architecture	<i>Aspect ratio, Number of floors, Window fraction, Window type, Orientation, Wall R-value, Roof R-value, Ground contact</i>
Equipment	<i>HVAC type, Boiler and/or chiller presence, Component efficiency, Control setting, Economizer type, CO₂ Sensor existence, Cooling tower type</i>
Operations	<i>Schedule, Occupancy, Ventilation Rates, Lighting density, Plug load density</i>

Two different types of parameters are considered in the database. Some parameters apply to the whole building (e.g. : *Number of floors* or *Aspect ratio*). Other parameters such as *Occupancy*, *Ventilation rates*, *Plug load density* and *HVAC type* apply to different functional spaces defined within the building's main activity. Functional spaces are defined for each main buildings activity. For example, an office building has eight functional spaces such as "Corridor", "Conference Room", "Office" and "Indoor parking". The main building activity "Education" includes also functional spaces such as "Classroom" and "Gymnasium".

The structure of the archetype database is such that the definition of the parameter values is very flexible. The values of these parameters are attributed based on each of the independent variables. It is therefore possible to attribute a parameter value based on a building's main activity and/or floor area and/or year of construction. Also, an equation, function of a building's construction year and/or floor area, could be used to represent this value.

In addition, each parameter value has a weight representing the possible distribution of the value of the parameter. In the "Single Building" mode, the chosen value of the parameter will be the value with the highest weight. In the "Building Stock" mode, the value will be randomly chosen based on the weight of each possible value.

Example

To illustrate the structure of the database, certain records linked to the values of two parameters were selected and are shown in Tables 2 and 3. These two parameters apply to the whole building.

Table 2 contains the values of the *Window fraction* (WinFr) parameter for buildings where the main activity is "Office". It should be noted that three values are possible for this parameter. These values are defined by equations that depend on the floor area (AREA). The empty fields "Floor area", "Location", "Heating source" and "Constr. year" indicate that the specified values apply to all floor areas, all locations, all heating sources and all years of construction. In the case of an office building of 1 000 ft², the chosen value of the WinFr parameter in the "Single Building" mode would be 18% ($0.28 - 0.099 * \text{EXP}[-1\ 000/42\ 156]$) because the weight associated with this value is the highest (1.01 vs. 1.00 and 1.00). In the "Building Stock" mode, the chosen value would be randomly chosen between the evaluations of these three variables with approximately the same probability because the weights are relatively similar.

Table 2: Example of the Window fraction value

ID	Parameter	Building activity	Floor area	Location	Heat. sour.	Const. year	Value	Weight
186	WinFr	Office					$= 0.17 - 0.039 * \text{EXP}(-\text{AREA}/9276)$	= 1.00
187	WinFr	Office					$= 0.28 - 0.099 * \text{EXP}(-\text{AREA}/42156)$	= 1.01
188	WinFr	Office					$= 0.4 - 0.151 * \text{EXP}(-\text{AREA}/19999)$	= 1.00

Table 3 presents the values of the *Ground contact* (Gnd) parameter for buildings where the main activity is "Education". The possible values are 'S' (Slab on grade) and 'B' (Basement). It should be noted that the weights of the 'S' and 'B' configurations are different for the years before and after 1969. In the case of a school of 10 000 ft² built prior to 1969, the chosen value of the Gnd parameter in the "Single Building" mode would be 'S' because the weight associated with this value, following evaluation, is higher than the weight associated with the 'B' value.

This approach provides a good deal of flexibility in terms of attributing values. Among the 70 parameters that are specific to buildings, several values and their conditions, as seen in the previous examples, are defined in the database. The next section discusses the analysis that was conducted to define these values.

Table 3: Example of the Ground contact value

ID	Parameter	Building activity	Floor area	Location	Heat. sour.	Const. year	Value	Weight
280	Gnd	Educat				<= 1969	=S' = 0.68 - 0.37 * EXP(-AREA/69862)	
281	Gnd	Educat				<= 1969	=B' = 1 - (0.68 - 0.37 * EXP(-AREA/69862))	
282	Gnd	Educat				> 1969	=S' = 0.2 - 0.195 * EXP(-AREA/45698)	
283	Gnd	Educat				> 1969	=B' = 1 - (0.2 - 0.195 * EXP(-AREA/45698))	

DATA SOURCES

The major part in the development of the functionality was the evaluation of the representative parameters. As a rule, it is difficult to obtain reliable data in a standard format that is easily adaptable to characterize a building. Data from different sources can seldomly be crossed and several engineering hypotheses and rule-of-thumb must be used to compensate for the lack of information. This particular characterization is not immune to these difficulties. However, several important studies conducted by Hydro-Québec in the past contain a lot of significant information that can be used.

The characterization of Québec's real estate stock is essentially based on analyzing the following three sources of information:

Programme d'analyse énergétique des bâtiments 1991-1997 [PAEB]:

Detailed energy analysis reports on over 14 000 commercial and institutional buildings in Québec based on a comprehensive audit conducted by a group of engineers and technicians.

Suivi des comportements énergétiques – Marché commercial -1992 [SUIVI]:

A telephone survey conducted by a team of investigators on a sampling of 2 651 buildings throughout Québec.

Dossiers de soumission au programme incitatif d'Hydro-Québec [PEP]:

Over 400 projects were submitted to Hydro-Québec's incentive programme between 2004 and 2007. Each project included an energy simulation file that is compatible with the SIMEB software.

Up till now, the parameters associated with the main building activity "Education" and "Office" have been processed. The following table provides the number of samples from each data source.

Table 4: Number of samples by data source

Source	Number of Samples		
	Office	Education	Total
[PAEB]	1504	803	14 821
[SUIVI]	339	379	2 651
[PEP]	118	108	400

Table 5 shows the origin of the values of certain parameters according to the different data sources that were used.

Table 5: Source of certain parameter values

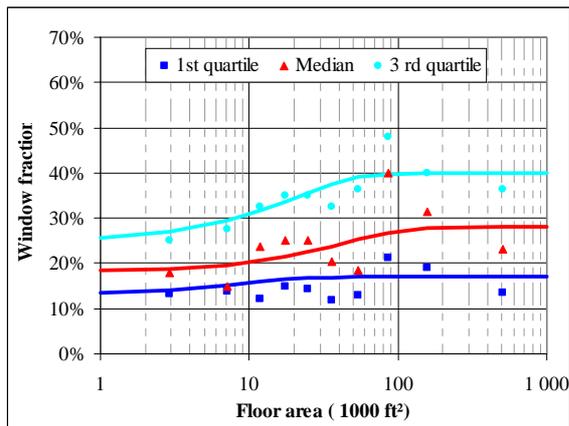
Source	Parameters
[PAEB]	<i>HVAC type, Lighting density, Economizer type, Boiler and chiller presence, Chiller type, Cooling tower type</i>
[SUIVI]	<i>Orientation, Basement existence, Number of floors, Window fraction, Schedules</i>
[PEP]	<i>Aspect ratio, Number of floors, Window fraction, Functional space area</i>
Others	<i>Plug load density, Ventilation rates, Occupancy, Schedules, Component efficiencies, HVAC controls, CO₂ sensor presence, Wall R-value</i>
- ASHRAE 90.1	
- Rule of thumb	
- Quebec Regulation on respecting energy conservation	

Example

An example showing the analysis of the value of the *Window fraction* (WinFr) parameter is presented for buildings where the main activity is "Office"

By combining the data sources [SUIVI] and [PEP], a sampling of 394 office buildings with a *Window fraction* value within the acceptable limits was selected. An analysis was conducted to determine the trend of the parameter based on the independent variables mentioned above. In the case of this specific parameter, there is a significant relation with the floor area. The *Window fraction* values associated with the 1st quartile, median and 3rd quartile are determined for each of the 10 groups defined by the deciles of the population in terms of floor area. In this particular case, each group contains approximately 39 office buildings. The graph in Figure 2 shows the 3 dispersion values for each central value of these 10 groups. Regression curves for the 1st quartile, median and 3rd quartile are then drawn.

Figure 2: Window fraction Analysis



This analysis was used to determine the values of table 2 in the previous example. In this case, the variability of the parameter is characterized by 3 equations associated with the 1st quartile, median and 3rd quartile of the building stock. The weight of each equation is practically equivalent to 1. A weight slightly higher than 1 (1.01) was attributed to the median value in order to force its selection in the “Single Building” mode.

ARCHETYPE GENERATOR

A set of rules was defined to generate a building. These rules establish the zoning, architecture, occupancy and operations of the building by way of the parameters in the archetype database. This section provides an overview of some of the rules.

Zoning

The archetype generator defines the floor area occupied by each of the functional spaces available within the main activity of a given building. The generator uses a parameter in the archetype database that weights each functional space area. The characteristics of the functional spaces (floor area, lighting and plug load density, wall exposition, ...) are transmitted to the SIMEB software.

The thermal zoning of a given building is done by SIMEB software, which uses an on-board algorithm to create thermal zones from functional spaces area. The algorithm uses component areas of the building’s envelope (window, roof, exterior walls, slab) that are found in each functional space and applies usual modeling rules to establish the thermal zoning. Details on this algorithm are provided by Bellemare et al 2008.

Architecture.

Several simple assumptions were considered to define the general configurations of the archetype building. First, the building is shaped in a rectangle with its aspect ratio and number of floors defined by the parameters in the database. All the exterior walls,

regardless of their orientation, have the same window fraction. In addition, each functional space has a parameter that provides a weight to the building envelope components. Thus, “Indoor parking” is always in contact with the ground and “Corridor” is usually less exposed to exterior walls comparatively to other functional spaces.

Envelope

To simplify the specifications of the components of the exterior walls, it was chosen to characterize a wall by its R value, determined by a parameter in the database. Up till now, the configuration of all the walls is the same: a row of bricks, an air space of ¾ inches, rigid insulation and gypsum board. The R-value defined by the parameter is implemented in the simulation by modifying the thickness of the rigid insulation so that the wall assembly is provided with the specified insulation value.

Plant and HVAC

Only one boiler is generated if the presence of a boiler is identified by a parameter in the archetype database. The same rule applies for the chiller (only one), regardless of the building’s total floor area.

In general, only one type of HVAC system is used in the whole building. The type of system is determined by a parameter in the database and can either be a double duct system, a constant volume system, a VAV system or baseboards only. However, specific types of systems are used for particular functional spaces, such as “gymnasium”, “indoor parking” and “kitchen”.

VERIFICATION

The simulation results of a group of archetype buildings were compared to the real consumption of existing buildings analyzed in the context of *Programme d’analyse énergétique des bâtiments 1991-1997* [PAEB]. This exercise allowed to compare the average and the diversity of the energy consumption obtained through archetype simulations and real data.

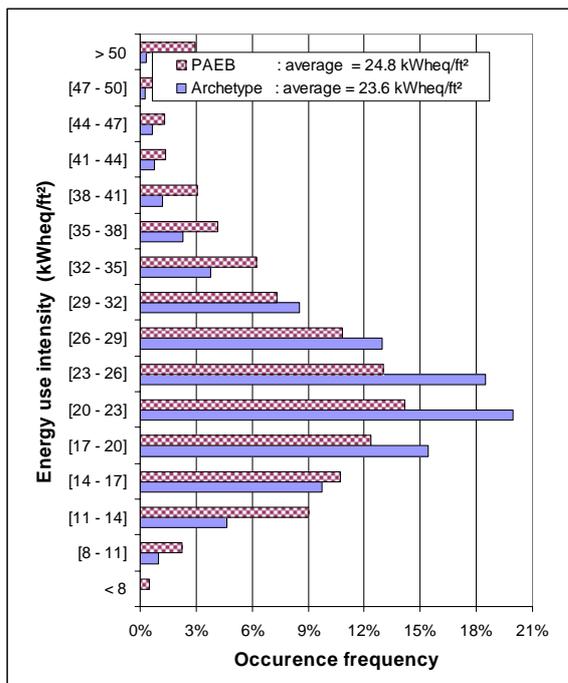
Several amounts of data are available on each of the buildings analyzed in the PAEB. This includes data associated with the independent variables of the archetype generator (main activity, floor area, year of construction, location, sources of energy, etc.) but also the normalized annual consumption by each of the energy sources and the estimated consumption by usage. For comparison purposes, a group of 1 396 office buildings were selected among the building stock in the PAEB. Based on the fundamental data (floor area, year of construction, energy sources, location) on each building, five archetypes were generated in the “Building Stock” mode, randomly attributing the value of certain parameters according to their distribution. Therefore, for each of the 1 396

selected buildings in the PAEB, five archetype buildings were randomly generated, which represents a total of 6 980 simulations.

Figure 3 illustrates the energy use intensity (kWheq/ft²) of the 1 396 buildings in the PAEB and of the associated 6 980 archetype buildings that were simulated. As shown, in the case of the simulated buildings, the dispersion levels are lower: two-thirds (67%) of the buildings consume between 17 and 29 kWheq/ft² compared to half (50%) of the office buildings in the PAEB. In addition, the average energy use intensity of the simulated buildings are slightly lower than those of the PAEB buildings (23.6 kWheq/ft² vs. 24.8 kWheq/ft²).

The difference in the distribution of the simulated buildings and the PAEB buildings is deemed to be acceptable in a first analysis. The disparity between the average consumption levels is less than 7%. As far as the variability is concerned, a greater amount of dispersion of parameter values could be input in the database. Indeed, the vast majority of the parameters whose variability has been included in the database do not cover the chosen extreme values, but the values related to the 1st, 2nd and 3rd quartile of their distribution. However, it is often very difficult to accurately represent the distribution of a parameter's value with the data sources that are available.

Figure 3: Distribution of the energy use intensity (kWheq /ft²) of the 1 396 PAEB buildings and the 6 980 simulated archetype buildings



The verification of the archetype building energy consumption has been done with relatively the same PAEB sample of buildings used to establish some parameter values (as depicted in table 5). However, we consider that the verification is acceptable because only general characteristics, such as HVAC types and chiller types, have been extracted from this sample and because the comparison is made on the overall annual energy consumption which was not taken into account in defining the archetypes.

DISCUSSION

The variability of the energy use intensity of buildings with the same main activity is significant. The former analysis of the PAEB buildings demonstrated that 50% of the analyzed office buildings rate outside the 17 kWheq/ft² - 29 kWheq/ft² range. This variability suggests that it is difficult to define one or a small set of “typical” office buildings that represent the entire group of buildings. In this sense, the archetype buildings establish a larger diversity and are more representative of the building stock.

The proposed approach does, however, have its limitations. A comprehensive characterization of the building stock would be necessary to obtain accurate results. Equally, the interdependence of the values of certain parameters should be investigated. For example, the *Window fraction* and *Window type* parameters could be correlated and therefore be dependent upon one another, but it is difficult to prove and determine this dependence with the available sources. A certain amount of vigilance is therefore required to ensure the global coherence of the generated building.

CONCLUSION

This article presented a functionality that generates simulations of commercial and institutional buildings with representative characteristics of a real estate stock. The purpose of this functionality, the process, the data sources and the significant assumptions leading to the creation of archetype buildings have been outlined. As of this date, the main building activities “Office” and “Education” have been characterized. The next steps will essentially deal with the characterization of other building activities.

The archetype building functionality has been integrated in the SIMEB simulation software developed by Hydro-Québec, which will be distributed free of charge in the near future.

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