CSA C873Building Energy Estimation Methodology- A simplified monthly calculation for quick building optimization

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Abstract

CSA C873 Building Energy Estimation Methodology (BEEM) is a new series of (10) standards that is intended to simplify building energy calculations. The standard is based upon the German DIN Standard 18599 that has 8 years of proven track record and has been modified for the Canadian market. The BEEM method relies on steady state heat balance equations using monthly averages instead of dynamic equations used in hourly software. The method then relies on utilization factors to calculate the contribution of heat gain on heating loads and includes a simplified algorithm for lighting savings associated with daylight strategies. The daylight algorithm is based on available climate data and detailed daylight modelling. The method was validated through the modelling of seven building archetypes in 6 different climate zones. Results from the BEEM modeling is compared to similar buildings modeled in CanQuest. Seven typical building archetypes were modeled in 6 different Canadian climate zones. These archetypes are different than the ASHRAE 140 or the BESTEST models with more zones defined and different HVAC systems. The intent was to compare the method for typical simple Canadian commercial buildings. An average of 8.5% difference on the overall energy consumption was found. Acknowledging there is a difference between energy modeling software results, this difference needs to be put in perspective with differences between energy modeling software and difference from energy modelling to real building consumption. BEEM has the advantage of offering a direct feedback to the user allowing for a real time optimization process. The intent of this method is to provide a tool for simple buildings that usually don't get modeled. The BEEM method is not intended as a replacement for the more detailed energy modelling simulation that is typically performed for larger or more complex buildings. The planned release date for the standard is March 2014. The CSA C873 Building Energy Estimation Methodology task force is considering the development of a software tool to assist with the adoption of BEEM for simple projects. The National research Council – Canadian Codes Centre is considering the standard as a path for demonstrating compliance with the National Energy Code for Buildings in 2015.

1   Background

The CSA C873 Building Energy Estimation Methodology (BEEM) was created with the intent of simplifying energy estimation calculations and to propose a uniform method for building energy calculations. The standard was adapted for Canadian locations and to account for differences in HVAC systems typically used in Canada. It is derived from the DIN Standard

18599 used in Germany for building code compliance. The DIN standard was constructed based on EN-ISO standards that were developed to standardize building energy consumption calculations in Europe. In 2002, the European Committee for Standardization (CEN) was mandated by the Energy Performance of Building Directive (EPBD) to develop a set of standards on energy performance in buildings to support the EU Member States for the national implementation of the EPBD.

Having a standard for building energy estimation homogenizes the algorithms behind the different tools available. Different energy modelling software can create different results, so from a legislation point of view there is an advantage to standardize energy modelling software. ASHRAE 140 Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs is currently the standard used in the industry to uniform energy modelling software's results. ASHRAE 140 covers limited cases and HVAC system configurations. The BEEM approach is working on standardizing the algorithm instead of validating results. Both ASHRAE 140 and BEEM are attempts to develop more consistency in energy modelling results and each has their pros and cons.

BEEM will not replace hourly calculation methods as complex building modelling and building research will require detailed and advanced modelling that cannot be performed with BEEM. As regulations on building energy performance become more stringent and far reaching, there is a need to model more simple buildings. Having a simplified, standardized method to evaluate energy performance of simple building could be a way to help the construction industry to meet demanding target for energy performance evaluation.

2 Calculation methodology

This section is an overview of the calculation process and briefly explains how monthly data can be used to calculate building energy consumption.

Standard Structure

The CSA C873 series is divided in 10 standards. The different standards are used to generate inputs for other parts or generate energy usage output.

- **C873.0: Definitions and general requirements for the calculation of energy loads, energy consumption, and source energy for heating, cooling, ventilation, domestic hot water, and lighting in buildings**
- **C873.1: General balancing procedures, terms and definitions, and zoning and evaluation of energy types**
- **C873.2: Energy loads for heating and cooling of building zones**
- **C873.3: Energy loads for conditioning air**
- **C873.4: Energy consumption for lighting**
- **C873.5: Energy consumption for heating systems**
- **C873.6: (reserved)**
- **C873.7: Energy consumption for air-handling and air-conditioning systems for**
- **non-residential buildings**
- **C873.8: Energy consumption for domestic hot-water systems**
- **C873.9: Energy consumption and source energy for combined heat and**
- **power plants**
- **C873.10: Boundary conditions of use—Climatic data.**
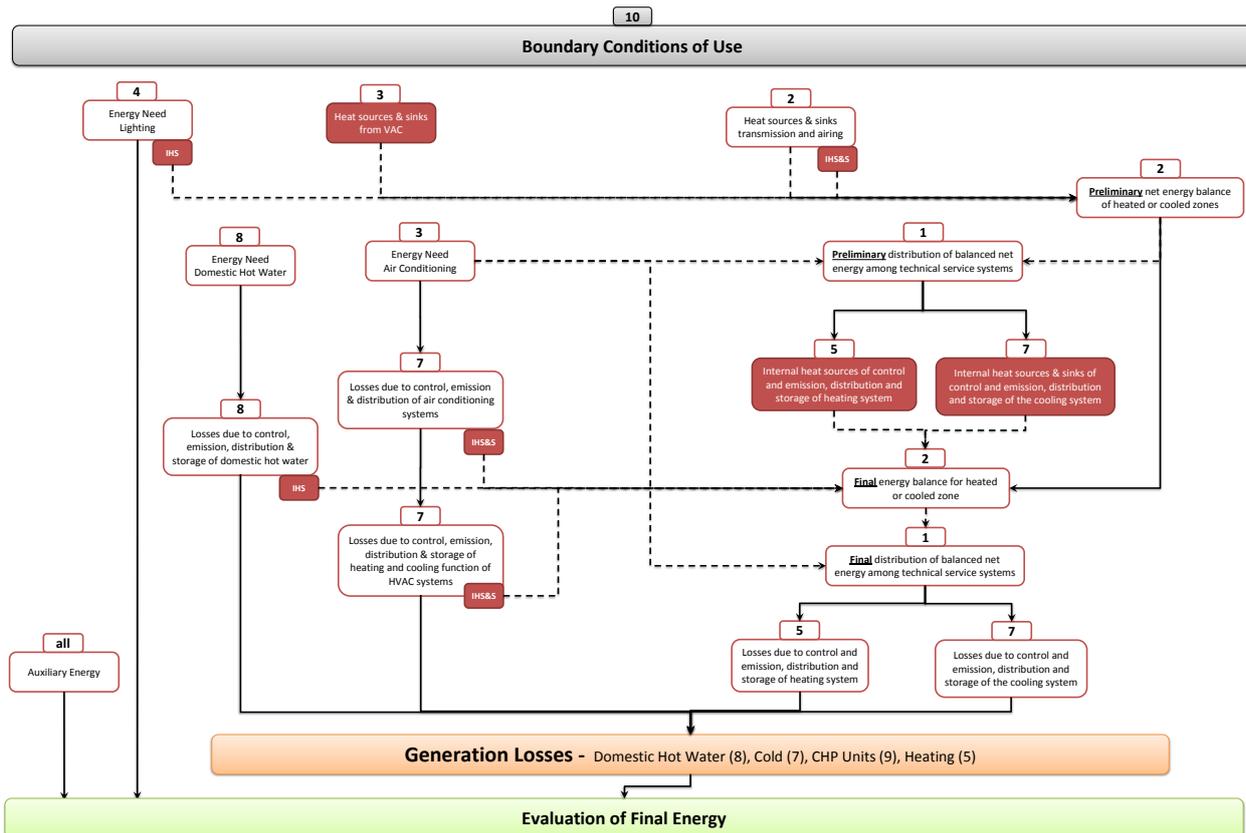
Figure 1: BEEM flowchart

Monthly data

Schedules from the National Energy Code for Buildings 2011(NECB) have been used to generate monthly utilisation time related to different internal loads and equipment (lighting, plug loads, people and ventilation).

CWEC weather files are used to calculate monthly average temperatures and solar gains.

Heating and cooling loads

The BEEM method relies on steady state heat balance equations using monthly averages instead of dynamic equations used in hourly software. This simplifies the heat transfer and heat balance equations but add complexities to HVAC and equipment operation calculations.

The load module for the BEEM standard relies on a correlation factor to determine the heating and cooling loads in the building and has the largest impact on the accuracy of the results. These correlation factors were developed for European locations so new correlation factors were used to better match results. Since it remains a correlation, there is a certain margin of error associated with the method. While European correlation factors were developed through real measurement and simulations, new factors for Canadian location were developed with a trial and error process. More parametric studies are currently underway to validate the algorithm for more boundary conditions.

The variation in the utilisation factor has a great influence over the heating and cooling load. It is the most important variable in the BEEM approach. The heating load ($Q_{h,b}$) is equal to the heat sink (or heat loss) minus a portion of the heat source (or heat gain). This portion is called the utilization factor. It indicates how much of the heat gain is contributing to the heating demand.

$$Q_{h,b} = Q_{sink} - \eta Q_{source}$$

Where:

$Q_{h,b}$ is the heating load
Q_{sink} is the sum of the heat gains for the entire month
η is the utilization factor
Q_{source} is the sum of the heat losses for the entire month

The utilisation factor is a function of the Gain-loss ratio (Y) and a parameter a:

$$\eta = \frac{1 - Y^a}{1 - Y^{a+1}}$$

$$a = a_0 + \frac{\tau}{\tau_0}$$

Where:

$Y = Q_{source}/Q_{sink}$ is the heat/gain ratio
τ is the time constant of the building zone

The a_o and t_o given in the method were changed to a_o=5 and t_o =15 in order to get a closer match with the CANQuest heating energy numbers. This formula was develop to correlate utilisation factor with the heat gain on heat loss ratio (variable Y). Sensitivity analysis are currently in progress to better understand the factors influencing the utilization factor.
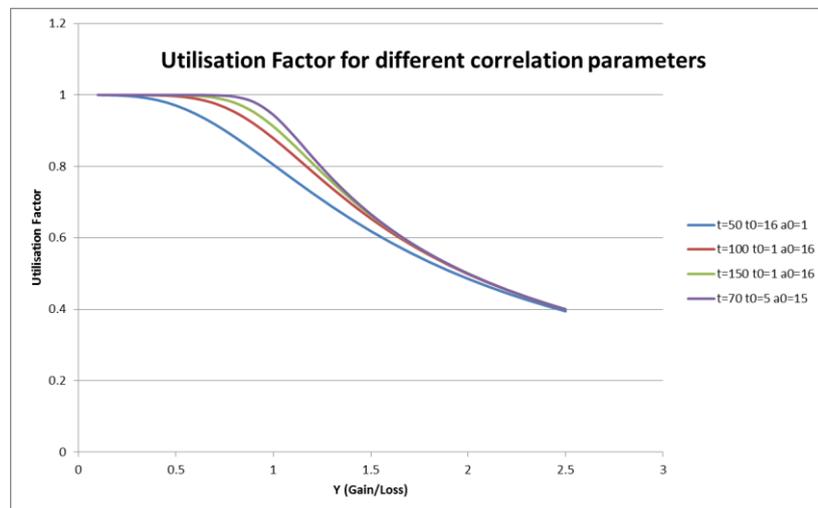
Figure 2: Utilization factor as a function

Figure 2 shows the relationship between the ratio of heat gains and heat loss and the utilization factor. When heat loss are dominant over heat gain (Y<1), we can see that the proportion of the heat contributing to the heating demand varies between 0.8 and 0.99. The time constant of the building, highly influenced by the building mass, has a direct impact on the utilization factor.

Advantages of reduced time-step

A reduced time step allows the generation of results in real time as inputs parameters are changed. This allows a real time optimization process where modifications to the building design can be evaluated immediately which will be a great advantage to the integrated design process. Simple buildings often have aggressive schedules where time is not available for some energy modelling software to run and compile series of parametric runs. The BEEM method could help improve the energy efficiency of simple buildings by reducing the time necessary to test design options.

3   Validation of BEEM

The application of BEEM was studied for seven different building types located in six Canadian climate zones. Results are compared to an hourly simulation done with CanQuest to validate the standard results.

Specifically, the following building archetypes were modelled:
- **Medium Office**
- **Large Office**
- **Strip Mall**
- **Big Box Store**
- **Warehouse**
- **Small Office**
- **Small MURB**

The 6 weather locations are Victoria, Windsor, Montreal, Edmonton, Fort McMurray and Yellowknife representing all Canadian climate zones.

BEEM models were based on building archetypes previously modelled for a study related to the National Energy Code for Building. Building input files from the CanQuest model help reproduce an exact set of inputs to be used in the BEEM method.

This comparison test is different than the ASHRAE 140 comparison test and the International Energy Agency Building Energy Simulation Test (BESTEST) with the intent of keeping a similar methodology. The intent was to use archetypes that represent the majority of the simple buildings built in Canada. These building types are also the target audience for BEEM.

The building archetypes have several zones with a variety of window to wall ratios from 3.5% to 40%. Variable and constant volume ventilation systems were modelled. Different sources of heat such as furnace heating and boilers were modeled. Chillers and Direct expansion cooling equipment were modeled.

Table 1: Inputs summary

Archetype	Small Office	Medium Office	Large Office	Big Box Store	Strip Mall	Warehouse	Large MURB
Number of zones	10	10	15	9	18	1	27
Window-to-wall ratio	40%	40%	40%	4%	20%	3.5%	40%

Single/multi zone	multi zone	multi zone	multi zone	single zone	single zone	single zone	single zone
Heating system	RTU furnace	RTU furnace	boilers	RTU furnace	RTU furnace	RTU furnace	boilers
Cooling system	DX	DX	Chillers	DX	DX	None	DX

4 Results

Outputs from the BEEM method were organized by energy end-use to allow a more detailed comparison to the CanQuest results. Total energy and energy end-uses are compared for the 6 different archetypes in 6 weather zones. Differences between the two methods are analysed looking at the overall percentage difference and the end-use difference.

Table 2: Overall percentage differences for all archetypes in all the climate zones

	Medium Office	Strip Mall	Big Box	Small Office	Warehouse	Large Office	Small MURB	
Zone 4	25.5%	12.6%	23.5%	28.1%	2.9%	10.6%	9.4%	**16.1%**
Zone 5	10.6%	8.8%	6.0%	3.9%	5.5%	9.0%	3.3%	**6.7%**
Zone 6	8.8%	7.0%	6.5%	3.9%	4.3%	6.5%	8.6%	**6.5%**
Zone 7A	8.3%	4.4%	7.9%	7.2%	3.2%	4.1%	11.3%	**6.6%**
Zone 7B	5.5%	14.2%	1.6%	4.4%	5.7%	1.2%	9.1%	**6.0%**
Zone 8	2.8%	12.3%	8.1%	0.3%	17.1%	16.0%	7.0%	**9.1%**
	10.3%	**9.9%**	**8.9%**	**8.0%**	**6.5%**	**7.9%**	**8.1%**	**8.5%**

Medium Office, Zone 5

	BEEM	CanQuest
Lighting	25.9	25.1
Plug Loads	27.8	27.3
Pumps & Aux.	0.1	0.1
Vent. Fans	14.6	16.9
DHW	4.5	4.2
OA	9.3	4.6
Space Heat	29.6	25.2
Cooling	14.2	10.6
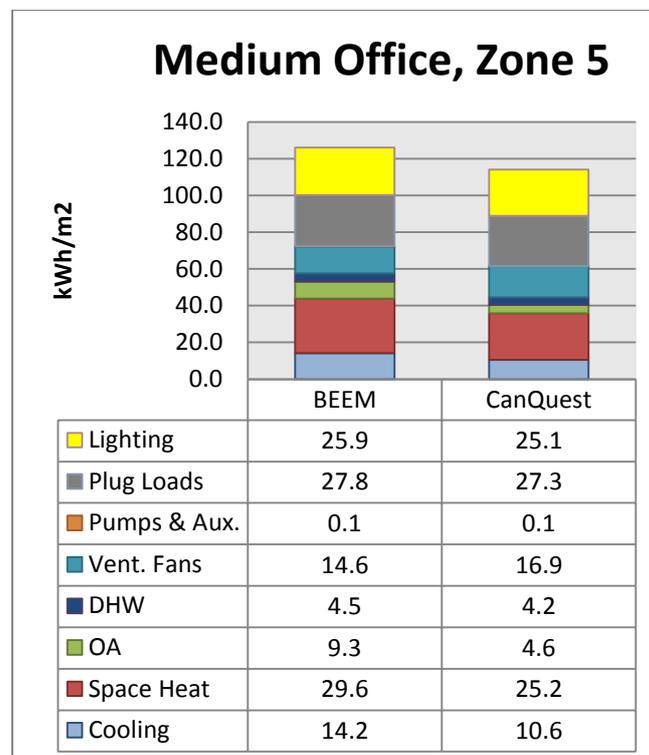
Figure 3: End-use difference for the medium office in climate zone 5

These results allows to identify areas of concern that needs further investigation. The algorythm for single zone constant volume system used in the strip mall and the big box store was identified as a possible cause of error.

5   Conclusions

The BEEM calculation procedure allows a "real time" energy optimization process. This can be an advantage in an integrated design process where design decisions are often made quickly without allowing sufficient time for traditional energy modelling analysis.

Overall results of all archetypes show that total energy difference average is 10.7%. The energy end-use results identified heating as the end-use with the largest deviation from the hourly simulation results. Utilization factor and single zone unitary systems were identified as possible causes for this difference. This will help focus future work to optimize the BEEM algorithms for the Canadian climate and lower the difference between the results.

Acceptance of results should be put in context with the intent of the method. ASHRAE 140 does not set a specific number, but leaves the organization referencing the method of test with some guidance such as overall magnitude, the magnitude between cases and sensitivity.

Next steps for the validation will be to compare the sensitivity of the BEEM and CanQuest models for different inputs variations such as internal loads, window wall ratio and envelope.

6   References

P. Wouters, L. Vandaele (Eds.), *PASSYS Final Report*. Office for Official Publications of the European Communities, DGX11, 1993.

Dandan Zhu, Tianzhen Hong, Da Yan, Chuang Wang, *A detailed loads comparison of three building energy modeling programs: EnergyPlus, DeST and DOE-2.1E,*Tsinghua University Press and Springer-Verlag Berlin Heidelberg, 2013.

Juha Jokisalo*, Jarek Kurnitski, *Performance of EN ISO 13790 utilisation factor heat demand calculation method in a cold climate, ELSEVIER, 2006*

Dick van Dijk, Marleen Spiekman, *CEN Standards for the EPBD – Calculation of energy needs for heating and cooling, INIVE,* *http://www.inive.org/members_area/medias/pdf/Inive/IAQVEC2007/VanDijk.pdf*

Judkoff R. , Neymark J.*, International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method,* National Renewable Energy Laboratory, 1995

ASHRAE*, ANSI/ASHRAE Standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.* Atlanta, USA: American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2007