Evaluation and Optimization of Office Buildings Energy Performance in Cold Climate

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The paper presents methodology for building energy performance analysis and energy saving measures evaluation, based on calibrated simulation. Methodology includes evaluation of investment, operational, and maintenance costs. Against the created baseline various individual energy saving measures are evaluated. Furthermore, three scenarios with different ECM combinations are evaluated, including Scenario 1 designed to meet minimum industrial standards, Scenario 2 designed to achieve cost-neutral GHG emission reduction in 25 years, Scenario 3 designed to achieve the maximum GHG emissions reduction irrespective of the costs. The methodology has been verified on the example of office building in cold climate - Winnipeg, Canada. The building energy model has been developed using IES VE software and verified using actual building operational data.

Introduction

Building energy performance analysis and evaluation of energy conservation measures (ECMs) are complex tasks requiring a methodical approach which includes utility analysis, calibrated building energy simulation, and lifecycle costs analysis. This paper gives a short overview of the new methodology based on calibrated building energy simulation as an indispensable tool [1,2]. Methodology was tested on the example of Winnipeg Tax Centre building in Winnipeg, Canada.

Building energy model

Analysed building is a two-story office building constructed in 1979, with gross area of around 32.000 m² and 2.500 occupants (Figure 1). Building has hot water heating provided by three natural gas fired condensing boilers with 880 kW maximum output each, chilled water cooling provided by three air-cooled chillers with 275 kW output each, and ventilation system which comprises of 17 air handling units supplying mixed air to zone VAV boxes (Figure 2). Building includes other minor HVAC systems and components which are also modelled, such as server room cooling system, printing room etc.

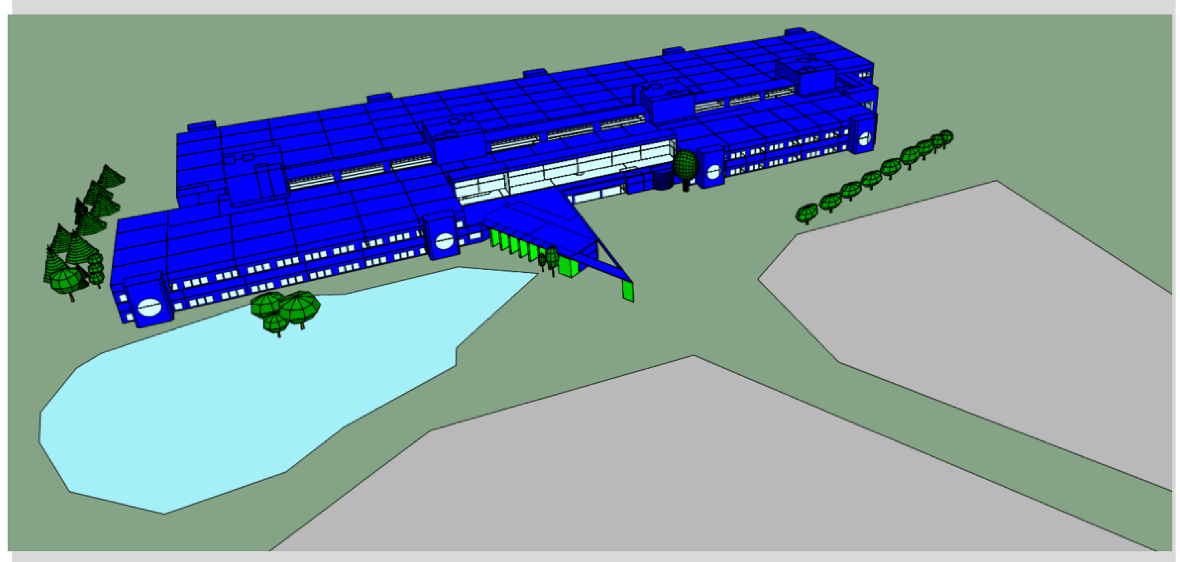

Figure 1. – Winnipeg Tax Centre 3D Model in IESVE Software

Building physical and mathematical model used for dynamic simulation includes heat conduction and storage, McAdams external convection model [3,4], long-wave radiation heat transfer, solar radiation, and various internal heat gains. Extensive building information is incorporated in the model, including building geometry, building envelope thermophysical properties, space usage types and occupancy, and building energy systems including HVAC and lighting.
Main building systems represented in the model, including their respective sequences of operation, are boiler plant, chillers, and ventilation system.
Building model thermal zoning fully reflects as-built condition, with all existing terminal equipment represented in the model. Over 345 thermal zones are incorporated in the model. Each zone is represented as a thermal node. The model is created and simulated using actual weather data with IES VE modular software environment [5].

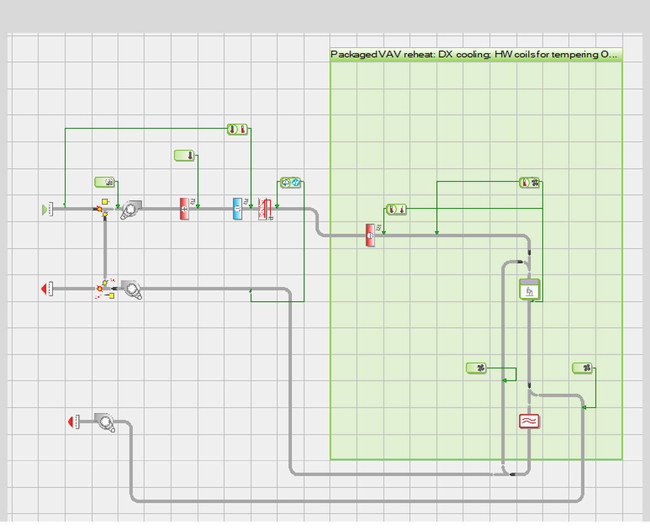

Figure 2. – Ventilation System Schematics (Typical of 17)

Utility analysis and calibrated simulation

ASHRAE Guideline 14-2014 [6] defines calibration procedure according to the monthly utility bills, which provide information regarding total energy consumption for natural gas and electricity and maximum electrical peak demand.
Approach presented in this paper uses also hourly metered electrical data in the calibration process. This enables calibration not only according to peak demand and total consumption, but also to hourly electrical demand.
Two indices were used to represent how well a mathematical model describes the variability in measured data.
Coefficient of Variation of the Root-Mean-Square Error (CV[RMSE])

$$\mathrm{CV(RMSE)} = \frac{\sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{(n-p)}}}{\bar{y}} \qquad (1)$$

Normalized Mean Bias Error (NMBE)

$$\mathrm{NMBE} = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{(n-p)\times\bar{y}} \qquad (2)$$

For calibrated simulation, the CV(RMSE) and NMBE of modeled energy use were determined by comparing simulation predicted data to the data used for calibration, with p = 1. Total energy calibration metrics are ilustrated on Figure 3 and Figure 4.

Table 1. – Calibration Results

	NMBE [%]	CV(RMSE) [%]
Electricity Energy	2.4	4.5
Electricity Demand	-1.6	10.1
Acceptable Range	±5	±15

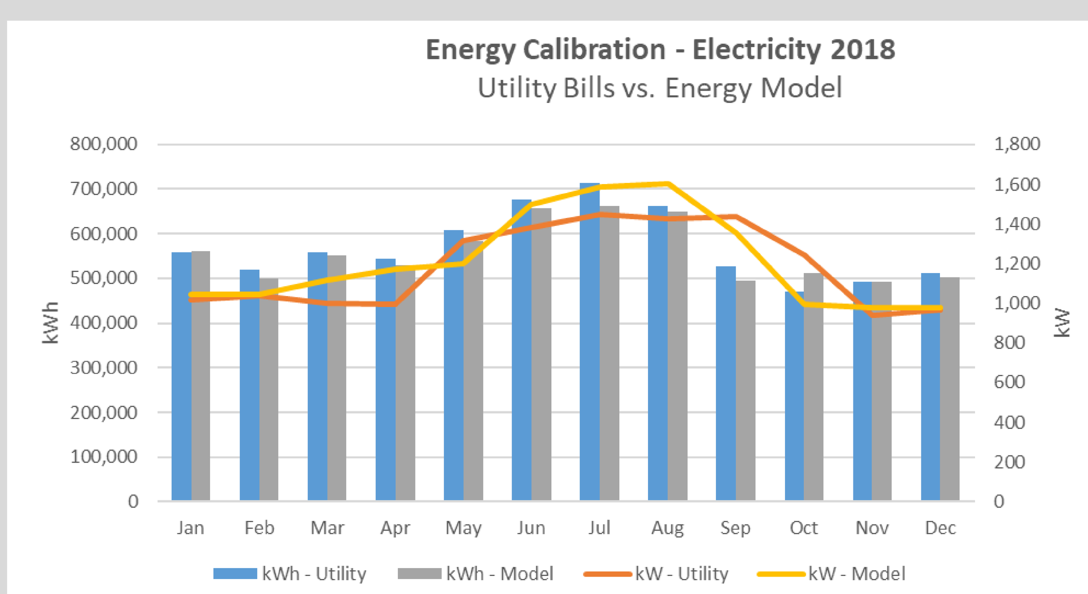

Figure 3. – Utility vs Energy Model Results for Electrical Energy

	ASHRAE 14-2014	
	NMBE [%]	CVRMSE [%]
Total Energy	1.7%	3.9%
Acceptable Range	±5%	±15%

Figure 4. – Total Energy Calibration Metrics

Individual energy conservation measures evaluation

Total of 34 ECMs were evaluated against building baseline, targeting envelope, HVAC systems, and building electrical systems. All envelope measures have negative Net Positive Value (NPV) over 25 years. The highest NPV over 25 years are for HVAC ECMs with dedicated outdoor air system and heat recovery. Geothermal heat pumps provide the highest GHG emission reduction.

ECM scenarios

Three scenarios with multiple ECMs, have been developed. Scenario 1 with 24% lower energy consumption than NECB standard [7], Scenario 2 is cost-neutral (25) years GHG emission reduction, and Scenario 3 designed to achieve the maximum GHG emissions reduction irrespective of the costs.

Table 2. – Bundle ECM Options results

Scenario		1	2	3
Electrical Savings	[%]	9	20	33
Natural Gas Savings	[%]	84	98	100
Total En. Savings	[%]	31	53	62
GHG Reduction	[%]	82	96	99

Conclusions

The presented methodology enables comprehensive evaluation of individual ECMs and ECM bundles, according to energy, environmental, and economic parameters. Also, as compared to conventional calibration approach, it also allows for better correlation between model results and the actual energy consumption, including unoccupied hours. Evaluation of ECMs shows that despite general expectations, envelope measures for office buildings are not cost effective and could provide only minor energy savings. Maximum GHG emission reduction is possible only via extensive use of renewable energy sources, and negative NPV over 25 years. The base model was used as the reference for comparison with the sustainable retrofitting strategies, in which extensive green roofs or intensive green roofs were implemented on all buildings. Except the implementation of green roofs, other parameters of the model were not altered.

Acknowledgements

This research was performed in the scope of the project GOC991245 of the Government of Canada and supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, under Contract 451-03-68/2020-14/200105.

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