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Development of Energy Benchmarks Using Mandatory Energy and Emissions Reporting Data: Ontario Post-Secondary Residences

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Abstract**—**Governments are playing an increasingly active role in reducing carbon emissions, and a key strategy has been the introduction of mandatory energy disclosure policies. These policies have resulted in a significant amount of publicly available data, providing researchers with a unique opportunity to develop location-specific energy and carbon emission benchmarks from this data set, which can then be used to develop building archetypes and used to inform urban energy models. This study presents the development of such a benchmark using the public reporting data. The data from Ontario's Ministry of Energy for Post-Secondary Educational Institutions are being used to develop a series of building archetype dynamic building loads and energy benchmarks to fill a gap in the currently available building database. This paper presents the development of a benchmark for college and university residences within ASHRAE climate zone 6 areas in Ontario using the mandatory disclosure energy and greenhouse gas emissions data. The methodology presented includes data cleaning, statistical analysis, and benchmark development, and lessons learned from this investigation are presented and discussed to inform the development of future energy benchmarks from this larger data set. The key findings from this initial benchmarking study are: (1) the importance of careful data screening and outlier identification to develop a valid dataset; (2) the key features used to develop a model of the data are building age, size, and occupancy schedules and these can be used to estimate energy consumption; and (3) policy changes affecting the primary energy generation significantly affected greenhouse gas emissions, and consideration of these factors was critical to evaluate the validity of the reported data.

Keywords**—**Building archetypes, data analysis, energy benchmarks, GHG emissions.

I. INTRODUCTION

FROM 1990 to 2013, global energy consumption increased by 55% and is predicted to be on the rise in following decades [1]. Governmental actions and policies play a key component in decreasing the degree of acceleration of the globes energy consumption, which is why several countries started to implement mandatory Energy Reporting and Benchmarking (ERB). Energy reporting involves the continuous process of reviewing the energy consumption of a building, while energy benchmarking is used as to compare a building's energy performance with that of other buildings with similar characteristics [2]. The intention of ERB is to provide knowledge and to encourage building owners and managers in order to improve the energy efficiency of their buildings. Research has demonstrated the positive environmental and economic impacts benchmarking can produce for building stakeholders [3], [4] yet the benefits of benchmarking data can extend far beyond this to identify areas of unexploited energy efficiency, define policies more aligned with local needs, quantify environmental impacts from conservation methods [5], and in some cases to develop Urban Building Energy Models that best represent a desired sample area.

UBEMs are gaining popularity due to their ability to simulate energy reduction interventions at larger scales [6]. To create an UBEM it is necessary to define details about the building stock, including, construction assemblies, geometry, and HVAC efficiencies. The collection of this data for large urban areas can be difficult due to the diversity of buildings therefore UBEMs rely on building archetypes to easily represent a building stock. A building archetype is a model of the average building in a given sample. These models are typically defined by climate, period of construction, geometry and use of space. To ensure that the archetype model performs similar to a certain building type it is important to identify benchmark energy use intensity (EUI) that best represents the operation of the building and the climate its within.

Since 2000, the Office of Energy Efficiency in Canada has published several energy benchmark surveys. The Consumption of Energy Survey (CES) was the first survey that covered all provinces and was based on 2003 data. The CES focused only on Canada's universities, colleges, and hospitals. In following years, CES expanded to cover nearly all segments in the Commercial and Institutional sector. Recently, post-secondary buildings have been included in the "other" category, which makes it challenging to determine accurate benchmarks for these buildings.

In 2013, the Ministry of Energy implemented annual mandatory energy reporting for the Broader Public Sector (BPS) to help organizations better understand how energy is being used. This paper presents the results of statistical analysis of this data. The objective of the research is to develop local EUI benchmarks for institutional residence buildings that fall in ASHRAE's climate zone 6 of Ontario. The results will be used for future work to develop archetypes models for post-secondary buildings in Ontario.

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II. METHODOLOGY

A. Data Collection

The report used for this paper includes information gathered on 21,369 buildings in the province of Ontario's Broader Public Sector. Organizations required to report consist of municipalities, municipal service boards, school boards, universities, colleges, and hospitals. Each organization is broken into operation types as they normally contain buildings that serve different purposes. For this paper, only post-secondary institution residences are analyzed due to the lack of existing benchmark information for this building type.

94 such buildings have been included in Ontario's latest BPS energy report. Only institutions that are part of ASHRAE's climate zone 6 (Fig. 1) were considered, as the results from this analysis will be used to develop residence archetype models that are representative of this region. While climate zone 6 extends beyond Ontario, data were only available for buildings within the region shown in Fig. 1.

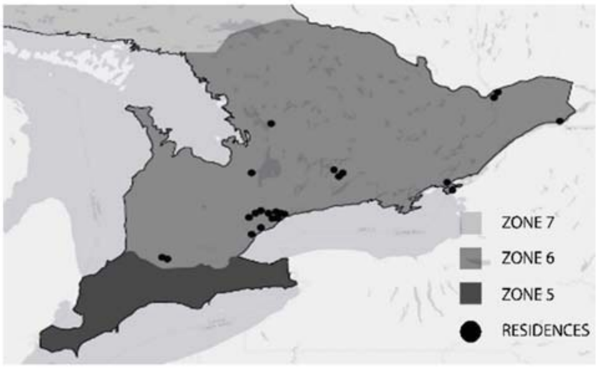

Fig. 1 Post-secondary residence buildings in Ontario's climate zone 6

The BPS energy reports used for this research contain detailed building information such as occupancy schedules, conditioned areas, GHG emissions and normalized EUI's for 2011, 2012 and 2013. Additional building characteristics were added to develop more significant correlations. Building shape was obtained using satellite imagery and geometry calculating tools, while construction periods were determined by means of experience and/or scientific literature.

B. Data Cleaning

Incorrect or inaccurate information complicates data analysis and if left unattended can lead to false conclusions. Since corrupt data is found in all data sources, unless proven otherwise, it is important to carefully review and remove and/or correct any suspicious entries. Before any detailed analysis was performed the data was checked analytically and visually to remove that which had obviously been corrupted. For example, if the EUI of a building varied by less than 50% or more than 200% of the previous and/or following years, the value was deemed erroneous and removed from the analysis dataset.

Box plots were used to identify outliers, as illustrated in Fig. 2. Before outliers were deleted, these plots were created using multiple variables and normalization factors (e.g. calculating emissions on an area basis) to ensure that data consistent with overall trends was not inadvertently deleted from the dataset. Once this verification was complete, these buildings with extremely high or poor performance were removed from the dataset to avoid biasing the benchmark.

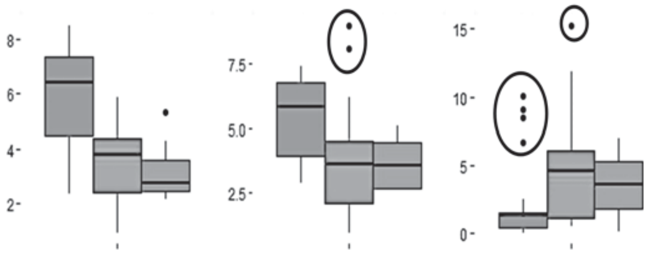

Fig. 2 Identification of outliers using boxplots

Through the climate segmentation and data cleaning process, the data from 38 buildings were determined to be unusable, resulting in a benchmarking sample size of 56 buildings, later broken down by construction period, occupancy schedules, and building geometry as illustrated in Tables I and II, respectively.

TABLE I
VARIABLES AND BUILDINGS INCLUDED IN BENCHMARKING ANALYSIS

Feature	Variables	Total Buildings
Construction Period	Pre-1980	23
	1980-2004	33
Building Geometry	Area	56
	Compactness	52
Weekly Occupancy Schedules	84 hours	4
	128 hours	4
	168 hours	48

TABLE II
AREAS CATEGORIZED BY SIZE RANGE

Category	Area (sf)	Pre 1980	1980-2004
A	Up to 50,000	4	8
B	50,001 – 100,000	10	8
C	100,001-150,000	6	12
D	150,001-200,000	3	3
E	200,001 +	-	3

C. Benchmark Development

In order to develop the benchmark, a forward multi-variable analysis was undertaken to determine which features (building attributes) significantly influenced the building energy consumption and greenhouse gas emissions. As noted in previous studies [7], these typically include climate, period of construction, and building size.

For each feature, the data was sorted using that feature as the differentiator using R – a python-based statistical analysis program with data shaping and regression capability. Box plots were used as a preliminary screening method to identify which features showed significant variation between categories. Once this was completed, the median, lower quartile (Q1), and higher quartile (Q3) values were recorded and have been included in the benchmark to provide end-users with an indication of how their building compares to the wider population.

III. RESULTS

The results from the analysis are presented in the following subsections.

A. Variation with Period of Construction

In order to have some granularity in the benchmark analysis the period of construction was broken down into two classes. These classes were selected due to the availability of data - majority of construction dates fall into the selected range - and to follow existing methods used by Natural Resources Canada (NRCan) in the development of the Canadian Urban Archetypes library.

The median, lower quartile, higher quartile and Interquartile range values obtained by using period of construction as a variable can be seen in Table III. The analysis shows that buildings that pertain to the Post-1980 category consume almost a third less energy than those built before 1980. These results could be linked to technological improvements in HVAC systems, appliances or operational efficiency measures, however the introduction and constant evolution of building energy codes, as they enforce construction practices that promote energy efficiency in cost effective ways, are likely to be an influential factor in the observed reductions.

TABLE III
EUIS BY PERIOD OF CONSTRUCTION

Period of Construction	Q1	Median	Q3	IQR	Units
Pre-1980	7.14	9.79	10.79	3.65	eWh/HDD/sf
1980-2004	4.71	6.13	7.72	3.01	eWh/HDD/sf

B. Variation with Building Geometry

The geometry of a building can have significant role on its energy performance.

Conditioned areas, building shape and exposed surfaces all influence the energy demand of a building. As only conditioned areas are part of Ontario's BPS energy reports additional geometric information had to be obtained. Using *Daft Logic* - an advanced distance and area calculator - areas, perimeters, and heights of all buildings were determined. Measured areas were then compared to the BPS reported areas, and if there were a difference greater than 20% the compactness of that building was not considered in the analysis.

A multi-variable regression analysis was performed to evaluate the relationship between energy consumption and building geometry. Building EUI was first plotted against building area and a weak correlation was indicated between decreasing EUI and increasing area. To obtain a stronger correlation, the period of construction and area ranges (summarized in Table II) were used as block variables and EUI was plotted against area, however correlations were still weak, as noted in the first column of R^2 values in Tables IV and V. In both tables, *n* is the number of buildings in the sample while the trend direction is indicated by + (EUI increases with increasing geometry variable) or – (EUI decreases with increasing geometry variable).

TABLE IV
R2 VALUES FOR EUI PRE-1980 BUILDINGS

Description	n	EUI vs A; Area only		EUI vs A; Area and shape		EUI vs C; Area and shape	
		R^2	Trend	R^2	Trend	R^2	Trend
A, TH	3	.23	+	.19	+	1	-
B, C-shape	4	.36	-	.009	-	.1	+
B, Tower	4			.29	-	.12	+
C, Tower	5	.16	-	.73	-	.73	+
D,	3	.34	+	-	+	-	

TABLE V
R2 VALUES FOR 1980-2004 BUILDINGS

Description	n	EUI vs A; Area only		EUI vs A; Area and shape		EUI vs C; Area and shape	
		R^2	Trend	R^2	Trend	R^2	Trend
A, Cross	6	-		.35	-	-	-
B, L-shape	3	.06	-	.91	-	.93	-
C, C-shape	4	.04 4	-	.72	-	.24	-
C, Z-shape	4			.02	-	.25	-
D,	3	.07	+	-		-	
E,	3	.50	-	-		-	

To develop more meaningful correlations, buildings were next grouped by shape. Eight different building shapes (Fig. 3) were defined based on the assessment of the existing sample. One shape group is omitted from this figure and includes all townhouse style residences less than three stories tall.

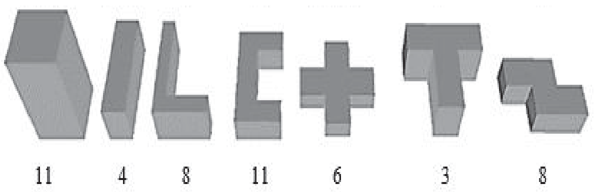

Fig. 3 From left to right: Tower, Beam, L-shape, C-shape, Cross, T-shape, and Z-shape buildings.

When grouped by both area and shape, strong trends began to emerge in the linear regression. Buildings were categorized by either area, or by a combination of area and building shape categories. EUI was then plotted area (A) and the strength of the correlation obtained by linear regression is summarized in the second set of R^2 values in Tables IV and V. These correlations are significantly stronger across both periods of construction. The trends in the data differ, however, suggesting that there may be further confounding factors that need to be incorporated in the model.

The ratio between floor area and enclosure area is often used to determine the compactness (C) of a building form [8]. The area of the enclosure is relevant as surfaces exposed to the environment offer paths for heat transfer to occur; hence a decrease in EUI as building compactness increases is expected. When EUI was plotted against compactness, the R^2 values decreased, implying that for this building type, area has a stronger impact in a building's EUI. Theoretically, two buildings with identical areas, operation schedules and occupant behavior, and building systems, but having different compactness values would see a significant impact of compactness on EUI, with the more compact building using less energy due to reduced envelope losses and gains. In this real case, however, it is challenging to identify the influence compactness has on its energy consumption given the multitude of unknown variables. To further investigate the impact of compactness, buildings were grouped by shape and both shape and area, (Tables IV and V, 3rd column of R^2 values) and one significant correlation was noted. It is noteworthy that to undertake this latter analysis, the data sets for each group became extremely small, thus limiting this investigation.

When one considers the significant variation in building occupant behavior – an aspect clearly visible in this study where a set of six identical buildings constructed at the same campus at the same time vary by up to 133% in energy consumption – it is not surprising that very strong correlations are not observed. The EPA's Portfolio Manager and Energy Star rating system database have R^2 values higher of only 0.33 [9] and four trends were noted that exceeded this value. Each of these trends noted a decrease in EUI with increasing area and with more compact buildings – findings consistent with building science principles. Should the quality of the reported data improve, a much larger data set will be available to develop better benchmarks and thus better inputs to UBEMs.

C. Variation with Weekly Occupied Hours

The majority (86%) of reporting buildings had scheduled occupancy of 168 hrs/week while the remainder were occupied 84 hrs/week (7%) or 128 hrs/week (7%). Analysis of this data showed a significant increase in energy use with occupancy hours, however there were too few data points for the less-occupied buildings, which prevented more specific analysis from being developed at this time.

IV. DISCUSSION

The energy benchmarking study presented herein identifies key issues with the use of mandatory building energy reporting as a data source for benchmarking. First, the variable data quality resulted in a significantly diminished data set. To an extent, this can be addressed through data cleaning and outlier identification as presented herein. This could be dramatically improved by implementing data verification and periodical energy audits.

The impact of building area, shape, and occupancy hours on energy consumption were investigated in order to provide more detailed benchmark values, however the small data set size limited the conclusions drawn and a larger sample is required to identify statistically significant differences using these categories. The period of construction, however, showed significantly different results. This level of granularity is consistent with the CES published data, thus the study has achieved its first goal of obtaining a benchmark for this building type to fill the existing gap.

It was extremely difficult to identify trends in GHG emissions because of the lack of reporting of primary energy sources, compounded by energy policy changes that influenced such sources [10]. At the macro level, the electrical grid changed substantially from 2011 to 2013 as coal-fired power plants were systematically decommissioned and replaced with wind and solar production, with gas-fired power plants to meet peak loads, however some institutions used cogen plants and did not see the effect of the changing grid. In addition, the institutions were not required to provide the detailed methodology used for GHG emission calculations and thus – particularly given the inconsistency of noted trends – the overall quality of this data set is suspect. Because of this complexity, greenhouse gas emissions have been omitted from this energy benchmarking study.

The results of this study have provided quartile benchmarks for post-secondary residence buildings by period of construction determined using publically available data. As more data is reported - particularly with improved quality control - there is significant potential to use this data to develop archetypal energy models for institutional residence buildings.

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