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Correlating energy consumption with multi-unit residential building characteristics in the city of Toronto

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ABSTRACT

Multi-unit residential buildings (MURBs) in City of Toronto, Canada, contain more than half of the dwellings in the City and are responsible for a significant proportion of the greenhouse gas (GHG) emissions associated with building energy-use in the residential sector. To efficiently reduce the impact of this sector, MURBs with the highest energy intensity need to be identified. Accordingly, this study examined correlations between building characteristics and energy use. A wide range of energy intensities were revealed and it was found that typology-specific energy-use trends could not be established. The energy intensity variability was attributed to differences in building operation and it was suggested that many buildings can realize improved energy performance by changing operating procedures. The building characteristics exhibiting the strongest correlations with energy use were fenestration ratio and boiler efficiency. However, the need for more uniform and complete building characteristic and energy use data was identified. This study concludes with recommendations to improve the quantity and quality of MURB energy-use data and building characteristics so that researchers can develop a more accurate and complete picture of the MURB energy-use in Toronto.

1. Background

The City of Toronto, Canada, is second only to New York City in terms of the total number of high-rise residential buildings [1]. Not surprisingly, these multi-unit residential buildings (MURBs) comprise 55% of the dwelling units in the City of Toronto [2]. It has been estimated that Toronto MURBs emit over 2.6 M tonnes of eCO_2 annually due to the combined electricity and natural gas consumption of these buildings [2], or more than 17% of the total annual greenhouse gas (GHG) emissions associated with natural gas and electricity consumption in the City in 2004 [3]. Thus, MURBs contribute significantly to the environmental impact of residential building energy use in the City of Toronto.

With over 2000 mid- and high-rise MURBs and approximately 4000 MURBs with fewer than five stories [2], this vast building stock represents a tremendous opportunity to reduce energy use and the resulting GHG emissions. Toronto has ambitious GHG emission reduction targets of 30%, based on 1990 levels, by 2020 [4] so MURB energy retrofits are a natural course forward to reducing emissions in the residential sector.

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1.1. Objective

This study was undertaken to determine how to easily identify MURBs with the highest energy intensity. In doing this, buildings with greatest environmental impact could be targeted first in order to efficiently reduce the impact of the MURB stock as a whole. To accomplish this objective it was necessary to determine the energy intensities of a large sample of MURBs and then to establish the building groups with the highest energy intensities. This way, policy recommendations targeting those groups with the highest energy intensities could be developed.

1.2. Approach

Many Toronto MURBs were designed and built during the 1960s and 1970s and, therefore, they exhibited similar architectural features and mechanical system characteristics. Accordingly, this study examined correlations between building typologies and energy use. Correlations between normalized energy use and building characteristics were sought using two distinct data sets. The preliminary data examined included buildings from three existing databases. A meta-analysis of this data was carried out, and it was concluded that additional energy data and more complete details about building characteristics were needed. A second, refined data set was assembled from the best quality data in the meta-analysis data set and then supplemented with buildings that were new to the study. Since this refined data set contained more detailed and comprehensive building information, it became possible to examine how various building characteristics, previously unexplored in the meta-analysis, affected energy use. The results of the search for correlations between similar basic building characteristics and energy use are reported here and the significance of the findings discussed. This paper concludes with a series of recommendations for researchers and policy makers on building energy data collection strategies and benchmarking practices so that better quality data can be used to develop policy interventions to efficiently reduce energy-use and GHG emissions in existing MURBs.

1.3. Previous work

A number of other studies, based on consumer-supplied energy data of MURBs in the Greater Toronto Area, have sought correlations between energy intensity and various characteristics such as building vintage, height and floor area. In these studies, which included less than 100 buildings, one showed no significant correlations [5] while another discussed observed correlations between energy intensity and building height, gross floor area and vintage without detailing the strength of these correlations [6]. Two studies showed a negative correlation between energy intensity and floor area [7,8]. One of these studies also indicated that privately-owned buildings, as opposed to public housing, had higher average energy intensities than public housing and that buildings heated with natural gas exhibit higher average energy intensities than those heated electrically [8].

Another study from the west coast of Canada and two other international studies were also examined. A study of 39 MURBs in British Columbia, found that buildings constructed after the 1990s used more energy than older buildings [9]. A Swedish study of 22 new buildings featuring similar design and construction showed correlations between MURB energy intensity and building shape factor and the size of the common areas [10]. A Korean study [11] found that energy use also varied according to the building shape as well as whether the building housed commercial space.

In this study, researchers sought a larger sample size compared to the previous investigations, described above, with the aim of developing stronger correlations. To the authors' knowledge, this work is the only Toronto-specific published study that examines correlations between energy use and envelope and mechanical system characteristics. These more detailed correlations are important for properly identifying the largest contributing factors to energy intensity. By identifying these factors, retrofit measures can be prioritized and new building code measures, such as decreased fenestration ratios, can be supported. Finally, all results have been normalized to the Canadian Weather for Energy Calculations (CWEC) so that other researchers can easily use these data to build upon this work in the future.

2. Building characteristics and energy-use data

Data were assembled from three existing data sets to form the meta-analysis data set and were later supplemented with more detailed data to form the refined data set. The characteristics of each data set are presented here along with details on how the data sets were used and the limitations that must be considered when reviewing the analysis.

2.1. Meta-analysis data set

In order to build on the work of others, existing MURB energy use data sets were sought. The meta-analysis data set combined energy use data and basic building characteristics from three different data sources. These existing data sets were derived from:

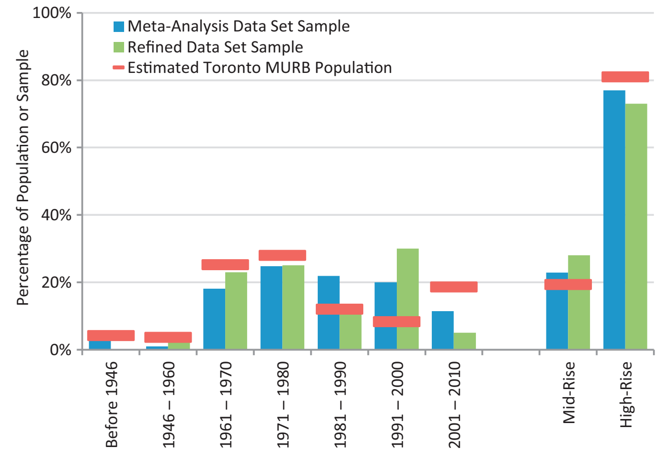

Fig. 1. Comparison of the height and vintage of the building sampled compared with the Toronto MURB population.

the Canada Mortgage and Housing Corporation's "High-rise Building Statistically Representative" (HiSTAR) Database and the Toronto Atmospheric Fund's Green Condo Champions Program and Tower Renewal Benchmarking Initiative.

This combined data set included 108 buildings, which represented an estimated 4.8% of the entire mid- and high-rise population and 1.8% of the total MURB population in Toronto [12]. Building construction dates ranged from 1941 to 2009. Building heights ranged from four to 46 storeys and gross floor areas ranged from 2000 m^2 to 101,700 m^2.

Considering the building heights and vintages sampled, the inventory from both the meta-analysis data set and the refined data set can be compared to an estimate of the entire MURB population in Toronto as shown in Fig. 1. The "percentage of sample" refers to the proportion of the total number of buildings in the particular data set that fall within a given category. Similarly, the "percentage of population" refers to the proportion of the total number of buildings in Toronto that fall within a given category. If the "percentage of sample" is larger than the "percentage of population", then that category is over-represented in the sample and vice versa.

The data for the number of Toronto buildings in each height and vintage category has been calculated by adjusting data derived from the TObuilt database [2]. The TObuilt database is an online resource which houses information on building characteristics for 1530 high-rise MURBs (greater than eight stories), and 125 mid-rise MURBs category (five to eight stories).

Limitations of the meta-analysis data set include a slight over-representation in the mid-rise category and a slight under-representation in the high-rise category. In terms of building vintage, the meta-analysis data set significantly over-represents the population of buildings constructed between 1981 and 2000.

With respect to the quality of the data, portions of the meta-analysis data set were incomplete or missing and the building characteristics data were not sufficiently detailed. In some cases, monthly electricity data were not available or only annual natural gas and electricity data were provided. Additionally, the meta-analysis data generally lacked information about mechanical system efficiencies and building envelope details.

2.2. Refined data set

A refined data set, composed of 40 buildings, was assembled to address the data limitations of the meta-analysis data set. More complete energy consumption data and information about building characteristics including parameters such as fenestration-to-wall