Development of Granular Archetypes for Canadian Existing Commercial Office and Multi-Unit Residential Buildings in Climate Zone 5

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Abstract

DOE Reference buildings consider two diverse time periods: pre-1980 and 1980-2004. However, within each, there is significant heterogeneity. Retrofit assessment requires a more granular set of archetypes. This paper presents a five-step methodology to develop such models for ASHRAE CZ5 commercial and multi-unit residential buildings, it starts by architectural styles analysis, followed by identifying representative building characteristics, the thirst step involves code review and data analysis, Subsequently, the methodology proposes the clustering of buildings that share common envelopes and finally the development of Energy Plus inputs for each identified cluster. The resulting clustering and envelope characteristics are presented in this paper along with the process used to create them. The resultant paper is valuable both to enhance ASHRAE CZ5 archetypes and to provide a replicable approach to enhance existing building archetypes.

Introduction

Globally, one third of the global energy consumption and greenhouse (GHG) emissions are driven from the buildings sector (IEA, 2024). To address the climate crisis, building retrofits will be key. While significant expertise exists to design individual building retrofits, their planning and optimization at the city scale remains a significant challenge. Urban building energy modelling (UBEM) has shown significant value to support such planning (Reinhart & Cerezo, 2016), however in the absence of individual building energy data, require archetype or prototype models that represent the built environment.

Significant research has been undertaken to develop models for existing buildings, notably the developed by the US Department of Energy (DOE, 2024) and Natural Resources Canada's Building Technology Assessment Platform (BTAP). Both used a bottom-up approach to characterize older (pre-2004) buildings, broken into two groups: pre-1980 and 1981-2004, and code minimum values from 2004 onwards. The lack of granularity for the older buildings is problematic in the Canadian context, where there are significant differences in architectural styles in each of these periods, driving significant envelope changes. Coupled with pivotal energy code changes in 1978, 1983, and 1997, it is clear that more granular archetypes are needed to develop more realistic urban energy models.

This paper partially addresses this challenge by developing a series of more granular envelope assembly archetypes to better reflect the diversity of pre-2004 construction in Climate Zone 5. This was undertaken through an architectural study to identify trends in building materiality and glazing, overlaid with a code analysis to determine the minimum thermal characteristics. Based on this analysis, a series of clusters has been developed for buildings other than single family housing; the latter have been omitted from this work because representative archetypes covering the spectrum of these building have been developed by others (Lawrence, 2020; Jermyn, 2008; Blaszak, 2010).

Methodology

In order to classify and characterize Toronto buildings, a necessary first step is to undertake an architectural analysis to identify and define key features differentiating each period. Next, the building envelope for each period is reviewed both qualitatively and by extracting relevant code requirements. Finally, a set of discrete building clusters is identified and defined, as discussed below.

Architectural Study

This study was informed primarily by a review of key architectural historical documents and studies, for example (Bozikovic and McHugh, 2017). To supplement this review, a database of historic buildings (Architectural Conservancy Ontario, 2024) was consulted and reviewed in the context of historical architectural styles to identify representative buildings from each period.

Each style was then documented as-follows. The visible envelope materials for walls and roof were noted, along with representative window types, shapes, and window-wall-ratio (WWR). Formal building features (e.g., roof shape, the use of columns or other symbolic elements, etc.) were also noted, along with any building components that could have a significant impact on energy use, for example protruding balconies connected to the main building structure that function as thermal bridges.

Building Envelope Analysis

While the style of a building can influence building energy through geometry, orientation, and WWR, the thermal properties are primarily determined by building materials, which is not possible to observe through an architectural study. Instead, a two-step process was used to characterize building envelopes. First, the architectural styles were reviewed to determine whether there were any features that

could impact energy consumption beyond the wall and roof assemblies and glazing systems. Next, representative values for such systems were determined, using building code requirements where relevant. Where no such requirement existed, typical construction practice from the period were used to determine representative assemblies, which were reviewed by experts in building assessment and retrofit.

Through the architectural style review, with the exception of large protrusions (balcony slabs, spires, etc.), ornamentation and detailing formed a minimal volume of the building envelope and thus are ignored in this study.

Prior to the first National Building Code (NBC) (Government of Canada. National Research Council Canada, 2022), the initial assumptions used in this research were that there was no insulation, and that the constructions were consistent with what was mandated by code. The rationale for this assumption is that the NBC was designed to ensure building safety and durability; poorly-constructed buildings that did not meet the code requirements are not expected to have survived the 84 years since it came into effect. While the NBC does not specify insulation for all buildings, it does specify minimum structural thicknesses. Because of the load-bearing nature of buildings in this period, these were documented and used to calculate expected thermal properties. With each subsequent code, the thermal properties, including envelope component RSI-values, glazing U-values, air exchange rates (ACH), and WWR where relevant, were documented. Each building was assumed to have been built to comply with code minimums.

Clustering Approach

The clustering of envelope archetypes is primarily based on historical shifts in building construction practices, distinctions building code thermal requirements, and significant architectural trends impacting form and window-wall-ratio over time. All buildings sharing consistent assemblies and thermal requirements were clustered together and their expected properties were tabulated.

Results

Toronto boasts a diverse array of architectural styles over the various periods of its history. Research into the architectural stock in the city of Toronto identified twenty distinct architectural styles, unique distinguishing features, and prevalent building materials. By cross-checking these against building code requirements, 15 distinct clusters were identified, reflecting five time periods ranging from before 1941 to 2004.

Cluster 1: Pre-1941

Prior to 1941, architectural styles were shaped by colonial trends (Grignon, 2015), with Georgian, Classical, Renaissance, Romanesque, and Gothic revival styles (see Figure 1); the latter featured predominantly in iconic buildings. These styles also influenced smaller structures.

During this era, the most common envelope was a double brick structure, without emphasis on insulation or thermal performance. Terracotta and concrete were also common building materials, used mainly in buildings that adapted the commercial and Art Deco Style.

Figure 1: Top to bottom: University of Toronto St. George Campus, Gothic Revival style, built: 1856 (Architectural Conservancy Ontario, 2023); Imperial Oil Opera Theatre, Renaissance Revival style, built: 1888 (Architectural Conservancy Ontario, 2023); Old City Hall, Romanesque Revival style, built: 1889-1899 (Bozikovic and McHugh, 2017).

While the styles of this period differ aesthetically, these differences are superficial, limited to detailing and ornamentation. They all share consistent heavy mass construction, low WWR, and lack of insulation, thus justifying their grouping as Cluster 1, whose properties are summarized in Table 1.

Table 1: Typical thermal characteristics for Cluster 1, for buildings built pre-1941

Cluster	**1**
Type & Style	Georgian, Classical, Renaissance, Romanesque, Gothic Revival styles, Commercial Style
Wall Assembly	Brick/ Stone/ Terracotta/ Concrete
RSI Walls	1.1
RSI Walls Below Grade	0.52
RSI Roofs and ceilings	2.75
RSI Floors	2.75
WWR	10%
Window Type	Single glazing
U value W/(m²K)	5
ACH@50 (Pa)	11.24*

**Represents an estimated value based on typical construction practices of the time*

Clusters 2, 3, 4 and 5: 1941-1977

This period was defined largely by the wartime and post-WWII period preceding the 1973 oil crisis. The first National Building Code (NBC) was established in 1941 to promote uniformity and standardize building regulations across Canada. This code played a pivotal role in construction projects during WWII and after the war when the demand for housing and building increased as a result of the substantial wave of immigration. This launched a period of significant development, which continued through the next three decades to accommodate the baby boomers. Architecturally, the 1950 and early 1960's saw a trend towards modernist architecture, characterized by clean lines, functional design, and an emphasis on durable materials like concrete, glass and steel (see Figure 2).

Later in the period, Canadian architects were influenced by Expo 67's creative and multicultural spirit, shaping their design approaches, and contributing to a more inclusive architectural identity. Expo 67 introduced innovative modernist designs, fostered international collaboration, and inspired architectural diversity. Modernism, Brutalism (Fig. 3) and the International style also began to become popular while Art Deco buildings continued into this period. Sharp differentiations in wall construction and WWR across styles resulted in four clusters to represent this period (Table 2).

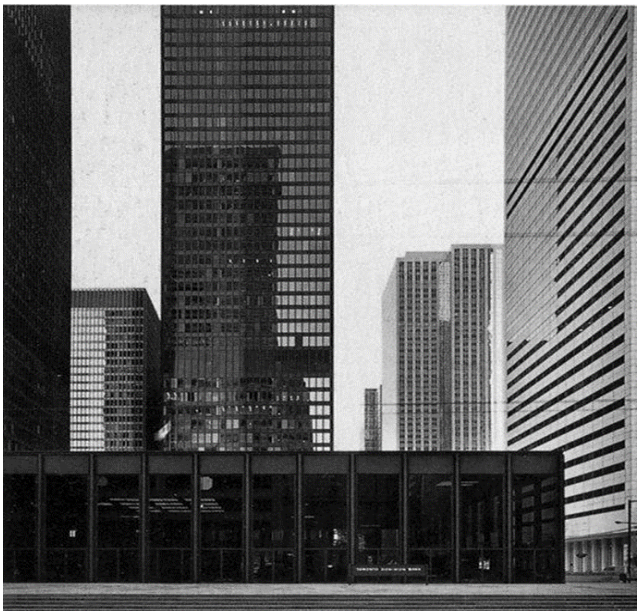

Figure 2: The high WWR, steel and glass Modernist style of Cluster 2 is represented by the Toronto-Dominion Centre, built 1963-1969 (Peter McCallum, 2023).

Figure 3: The heavy construction of the brutalist style is represented by this 1971 office building (Urban Toronto, 2023), representing Cluster 5.

While NBC specified construction requirements for all types of buildings based on the material assembly, building height, and occupancy, there were no insulation requirements and vapour barriers, while recommended, were not required. Glazing was single pane, and the as-built wall and roof thermal characteristics were assumed to be that provided by the structural material only.

Table 2 Typical thermal characteristics for Clusters 2-5, for buildings 1941-1977

Cluster	**2**	**3**	**4**	**5**
Type & Style	Small and Single-Family Residential Buildings	Commercial: International Style	Commercial: Art Deco, Modernist	Commercial: Brutalist
Wall Assembly	Wood frame with masonry or stone veneer, insulated	Steel and glass	Solid masonry bearing walls/ Reinforced concrete	Concrete walls (Thicker wall section)
RSI Walls	1.4	0.2	1.2	1
RSI Walls Below Grade	0.8	0.8	0.8	0.8
RSI Roofs and Ceilings	1.58	1.2	1.2	1.2
RSI Floors	1.4	1.4	1.4	1.4
WWR	10%	30 – 50%	40-60%	10-40%
Window Type	Single glazing	Single glazing	Single glazing	Single glazing
U value W/(m²K)	5	5*	5*	5*
ACH@50 (Pa)	11.24*	11.24*	11.24*	11.24*

**Represents an estimated value based on typical construction practices of the time*

Clusters 6 and 7: 1978-1982

The Oil Crisis of the 1970's led to a significant shift towards the awareness of energy conservation in building practices and the publication of the first edition of the Ontario Building Code – "Measures for Energy Conservation in New Buildings" (MENCB 1978). This marked a significant shift, from previous codes that did not have any energy efficiency requirements for non-residential buildings, introducing specific guidelines for enhancing energy efficiency in building design and construction.

The same architectural styles of the previous period appeared in addition to late modernism, postmodernism & Neo-modernism. WWR increased by code to 40% for all building types, so the switch to double glazing or triple glazing in the sense of meeting the minimum required U-value. Vapour barriers, air barriers & insulation materials became mandatory by all relevant codes to optimize RSI values & increase efficiency of buildings. The resultant thermal characteristics are summarized in Table 3.

Table 3: Typical thermal characteristics for Clusters 6-7, for buildings 1978-1982

Cluster	**6**	**7**
Architectural Style	Late Modernism and Postmodernism	
Building Type	All Buildings	
Wall Assembly	Brick veneer, w/ air space & insulation on steel or wood framing.	Solid masonry bearing walls with insulation/ Concrete wall with insulation
RSI Walls	3	1.9
RSI Walls Below Grade	1.6	1.6
RSI Roofs & Ceilings (Combustible)	4.7	3.6
RSI Roofs & Ceilings (non-combustible)	2.5	1.9
RSI Floors (Combustible)	4.7	3.6
RSI Floors (non-combustible)	2.5	1.9
RSI Slab on Grade (w/ embedded elements)	1.3	0.8
RSI Slab on Grade (w/o embedded elements)	0.8	0.8
Add for Building Assemblies Incorporating Thermal Bridges	20 % greater than the values above	
WWR	40%	

Window Type	Double glazing w/ 6mm air space or eq. to U value
U Value W/(M²K)	3.3
ACH@50 (Pa)	7.5*
Air Barrier	Yes
Vapour Barrier	Yes

**Represents an estimated value based on typical construction practices of the time*

Cluster 8 and 9: 1983-1996

In 1983, an update to the Measures for Energy Conservation in New Buildings document was released but there was no significant change to the architectural styles used. Clusters 8 & 9 are thus the same as clusters 6 & 7, respectively, with the new code requirements applied. Table 4 highlights the estimated thermal characteristics for each cluster in this period.

Table 4 Typical thermal characteristics for Clusters 8-9, for buildings 1983-1996

Cluster	**8**	**9**
Architectural style	Late Modernism; Postmodernism; Neo-Modernism	
Building Type	All Buildings	
Wall assembly	Brick veneer, with air space & insulation on steel or wood framing.	Solid masonry bearing walls with insulation/ Concrete wall with insulation
RSI Walls	3.6	3
RSI Walls Below Grade	2.2	2.2
RSI Roofs and Ceilings(combustible)	5.6	4.7
RSI Roofs and Ceilings(non-combustible)	3.1	2.6
RSI Floors (combustible)	4.7	4.7
RSI Floors (non-combustible)	3.1	2.6
RSI Slab on Grade (w/ embedded elements)	1.7	1.3
RSI Slab on Grade (w/o embedded elements)	1.3	0.8
Add for Building Assemblies Incorporating Thermal Bridges	20 % greater than the values above	
WWR	40%	
Window Type	Double glazing with 12mm air space or eq. to U value	
U value W/(m²K)	2.8	
ACH@50 (Pa)	7.5*	
Air Barrier	Yes	
Vapour Barrier	Yes	

*Represents *an estimated value based on typical construction practices of the time*

Cluster 10, 11, 12, 13, 14 and 15: 1997-2004

In 1997 the first Model National Energy Code for Buildings was published which emphasised on building envelope requirements in relevance to the heating /cooling source of the building (Canada, 2019). Cluster 10-12 defines thermal characteristic for small residential buildings, while cluster 13-15 is for all other types of buildings. Table 5 highlights the estimated thermal characteristics for houses while Table 6 highlights the estimated thermal characteristics for all other building types.

Table 5 Typical thermal characteristics for Clusters 10-12, small residential buildings constructed 1997-2004

Cluster	**10**	**11**	**12**
Architectural style	late modernism postmodernism and Neo-modernism		
Building Type Heating source	Electrical heated or others	Oil, propane, heat pump	Natural gas
Wall assembly	Brick veneer, with air space & insulation on steel or wood framing.		
RSI Walls	4.4	3	2.9
RSI Walls Below Grade	3.1	3.1	2.1
RSI Roofs (attic)	8.8	7	5.6
RSI Roofs (all other roofs, e.g., concrete)	5.2	4.3	4.3
RSI Floors	5.2	4.6	4.6
RSI Slab on Grade (w/ embedded elements)	1.9	1.9	1.9

RSI Slab on Grade (w/o embedded elements)	1.6	1.6	1.6
WWR	40-90%		
Window type	Double glazing with 12mm air space or eq. to U value		
U value W/(m²K)	2.4	2.6	2.6
ACH@50 (Pa)	3.5*		
Air barrier	Yes		
Vapour barrier	Yes		

**Represents an estimated value based on typical construction practices of the time*

The ASHRAE 90.1-2004 standard ("Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings") was incorporated as into the Ontario Building Code as a requirement without modification in 2006. This continued until the release of the Supplementary Standards SB-10 and SB-12 in 2012, which adapted the use of this code (or the MNECB) for Ontario buildings. Since 2004, the existing BTAP (Canada) and DOE Prototypical Building (USA) model sets include updates to each version of ASHRAE 90.1, which are updated every three years to reflect advancements in technology, changes in energy prices, and evolving environmental policy goals (Pembina Institute, 2015).

Overall, this series of clusters provides a more appropriate level of granularity for the characterization of building envelope constructions and are intended to provide energy modelers with a reference library that can be combined with other inputs (e.g. reference HVAC systems or reference internal loads and schedules) to create a set of granular archetypes representing as-constructed Canadian CZ5 buildings.

Building Characterization Summary

Fifteen different clusters have been identified based on the period of construction, building type, envelope assembly, architectural style and - after the late 1970's – HVAC energy consumption.

Figure 4 presents a comparison of the thermal resistance (RSI-values) of building envelopes in single-family housing and small buildings, while Figure 5 presents all other buildings.

Table 6 Typical thermal characteristics for Clusters 13-15, buildings other than houses constructed 1997-2004

Cluster	**13**	**14**	**15**
Architectural style	late modernism postmodernism and Neo-modernism		
Building Type Heating source	electrical heat or other	Oil, propane, heat pump	Natural gas
Wall assembly	Solid masonry bearing walls with insulation/ Concrete wall with insulation		
RSI Walls	3	2	1.8
RSI Walls Below Grade	2.4	1.7	1.3
RSI Roofs (attic)	7.1	5	5
RSI Roofs (parallel-chord trusses and joist-type roofs)	4.3	4.3	4.3
RSI Roofs (all other roofs, e.g., concrete)	3.4	2.4	2.1
RSI Floors (Parallel-chord trusses and joist-type floors)	4.5	4.5	4.5
RSI Floors (all other floors, e.g., concrete)	3.4	2.4	2.1
RSI Slab on Grade (w/ embedded elements)	1.08	1.08	1.08
RSI Slab on Grade (w/o embedded elements)	1.08	0.8	0.8
WWR	40-90%		
Window type	Double glazing with 12mm air space or eq. to U value		
U value W/(m²K)	2.8-1.7	3.4-1.8	3.4-1.8
ACH@50 (Pa)	3.5*		
Air barrier	Yes		
Vapour barrier	Yes		

**Represents an estimated value based on typical construction practices of the time*

These illustrate a progressive increase in RSI values up until the publication of the MNECB 1997, where RSI values were defined in reference to the heating fuel source or electrical loads of the buildings During this period, electric heating was discouraged because a) electric resistance, rather than heat pumps, were the common technology, and b) the province was still generating a large proportion of its electricity from coal (30% efficiency and high CO_2 emissions).

While of limited direct energy consumption impact, NBC began to require air barriers in 1985 (Daniel, 2016),

followed by air leakage rate requirements in the mid-1990s. Before these periods, literature reviews and expert consultations were used to determine the most likely envelope constructions and air tightness.

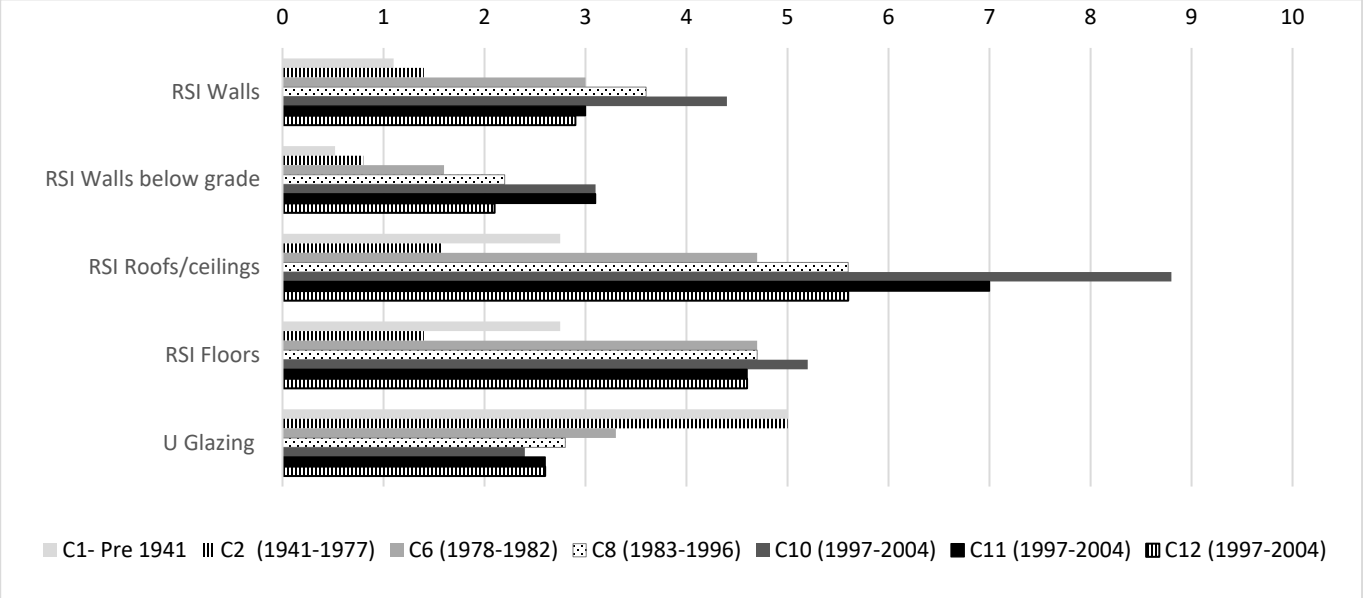

Figure 4: Evolution of thermal properties of single family and small buildings over time relevance to the code and construction advancement.

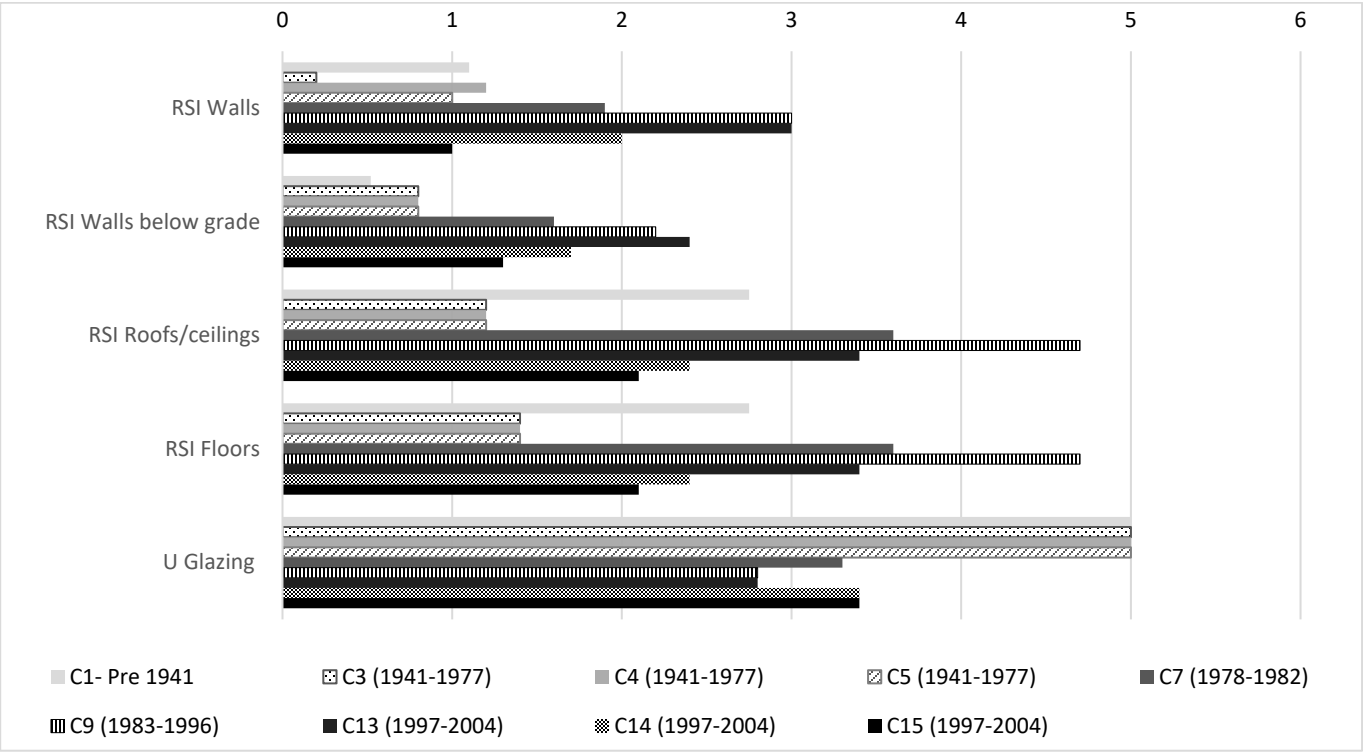

Figure 5: Evolution of thermal properties of buildings other than single family and small buildings over time relevance to the code and construction advancement.

Conclusion

By overlaying the key architectural developments with building codes, five distinct building periods were identified, which when combined with differences by building type, result in fifteen clusters to characterize buildings. cluster 1 represent brick buildings built pre1941, cluster 2,3,4,5 is for building built 1941-1977, a period affected by important historical events like WWII, EXPO 67, and the introduction of the international style that added

the new style of concrete & curtain walls structures to the Canadian architectural content. post 1978's clusters 6,7 that was affected by the 1973 oil crisis and marked a significant shift towards energy conservation, this period noticed increased window-wall ratios, the introduction of insulation and improved glazing properties. This improvement continued to appear over time as a response to the improved codes & energy efficiency requirements by law, appeared in clusters 8-15. By developing granular archetypes, more accurate inputs for energy modelling programs will be provided, which help in suggesting retrofit strategies to improve the energy efficiency of Canada's diverse building stock. This aligns with broader sustainability goals and the urgent need for a low-carbon future.

Acknowledgement

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