Energy Consumption Analysis of Architectural Design Decisions in BC.

Executive Summary Report

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Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of BC Housing staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of BC Housing or the University of British Columbia.

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Introduction

The construction industry is one of the most energy intensive sectors of any nation with construction activities (without life-cycle energy) alone consuming 38% of the global energy expenditure annually [1]. Given the sources by which we find a great deal of our energy in fossil fuels, natural gas, and coal - the more energy we use in any singular form, the more dependent we become on that energy source in the future - as we become more efficient at extracting this energy, building infrastructure to support it, and provide greater incentives to continue using it.

Cities need to make a concerted effort to reduce energy consumption in order to counteract the rising energy demand from urbanization and population growth. Residential energy requirements vary from region to region, depending on climate, dwelling type, and level of development. A large part of the life-cycle energy of a building (between 35–60%[2]) is used for heating, air-conditioning, ventilation, and artificial lighting, and so again, efficiency and proper sourcing is key.

This report has looked into the impacts of different architectural design decisions, in areas of variability such as wall assemblies, insulation, mechanical efficiency, window area and location - alongside other parameters relevant to the construction of a home in ceiling heights, floor area, volume, surface area and foundation types. All of these parameters and variables work to create unique results when exposed to different environmental conditions, creating archetypes that are more or less suitable for different climate regions - with three being studied here in Cranbrook, Fort Nelson, and Vancouver.

Background

There are important definitions to understand in order to reach a baseline understanding of different architectural configurations which can be found in the definition section of the main report. In the case of energy analysis, MEUI (Mechanical Energy Use Intensity) and TEDI (Thermal Energy Demand Intensity) are the most relevant to this report. TEDI, or Thermal Energy Demand Intensity, is a measure of the amount of annual heating energy needed per unit area required to maintain a building's interior temperature. It takes into account heat loss through the envelope and passive gains, such as the warmth generated by sunlight, body heat, and appliances. MEUI, or Mechanical Energy Use Intensity, measures annual energy consumption for the building's systems per unit area. This metric includes energy consumption from space heating, cooling, ventilation and domestic hot water equipment.

Differing climatic conditions (as the three cities are located in different climate zones) and different building conditions in both formal and mechanical measures will influence the efficiency of these metrics, among others such as utility costs, making some forms more efficient than others in different environments. These situations are discussed in the report and will be briefed in this summary.

[1/2] Yüksek, Izzet, and Tülay Tikansak Karadayi. "Energy-Efficient Building Design in the Context of Building Life Cycle." IntechOpen. IntechOpen, January 18, 2017. https://www.intechopen.com/books/energy-efficient-buildings/energy-efficient-building-design-in-the-context-of-building-life-cycle.

Summary

Energy Conservation Measures and Efficiency

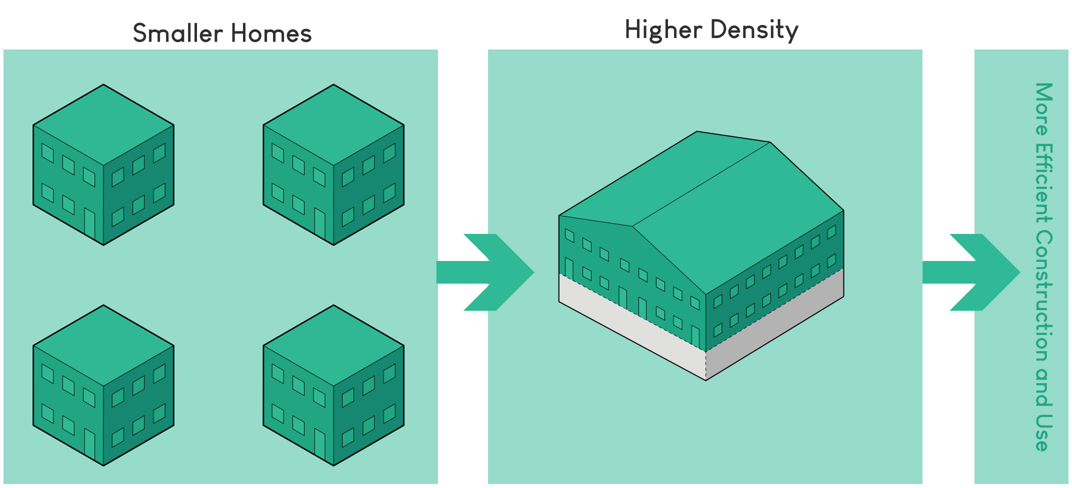
This section set all energy conservation measures equal to see what effect building shape, home size and foundation type have on the efficiency of a home. Through this section we can see that largest factors to a home's efficiency are related to the types of surfaces it presents to the outside, such as the difference between solid walls and transparent glazing assemblies, and home size and volume.

Surface area plays a great role in determining the efficiencies of a structure because the higher the external envelope surface area, the more opportunity for energy bridging between outdoor and indoor environments to occur (as heat energy wants to move from high energy (warmer) to lower energy (cooler) spaces.

Glazing area and percentages are important that they can allow sunlight and fresh air into a home, but can also allow heat to escape (as the window assembly is often less efficient than the wall assembly). Window placement is also important, as certain faces of the building will naturally receive more sunlight than others. As such, an efficient window assembly should be used in combination with solar shading or blinds to keep solar radiation from heating the interior of a home too much.

If we can take the strengths of both of these situations, it becomes apparent that living minimally, in both resources and space, combined with density, that is combining smaller living spaces into a single larger volume, and keeping the shape of a building as close to a square as possible (to maximize the volume to surface area ratios) is one of the more efficient means of making buildings in our geographical and urban context (Fig. 1). Further analysis of the abilities of natural ventilation, and factors such as microclimate analysis and passive architectural climate systems such as solar shading devices, can provide greater passive efficiency for a home, using far less energy compared to a mechanical system.

Figure 1. - Working towards living in smaller spaces while being in higher densities is an optimal solution towards creating energy efficient homes and minimizing land/environmental use and impact.



Summary

House Size and Overall Efficiency

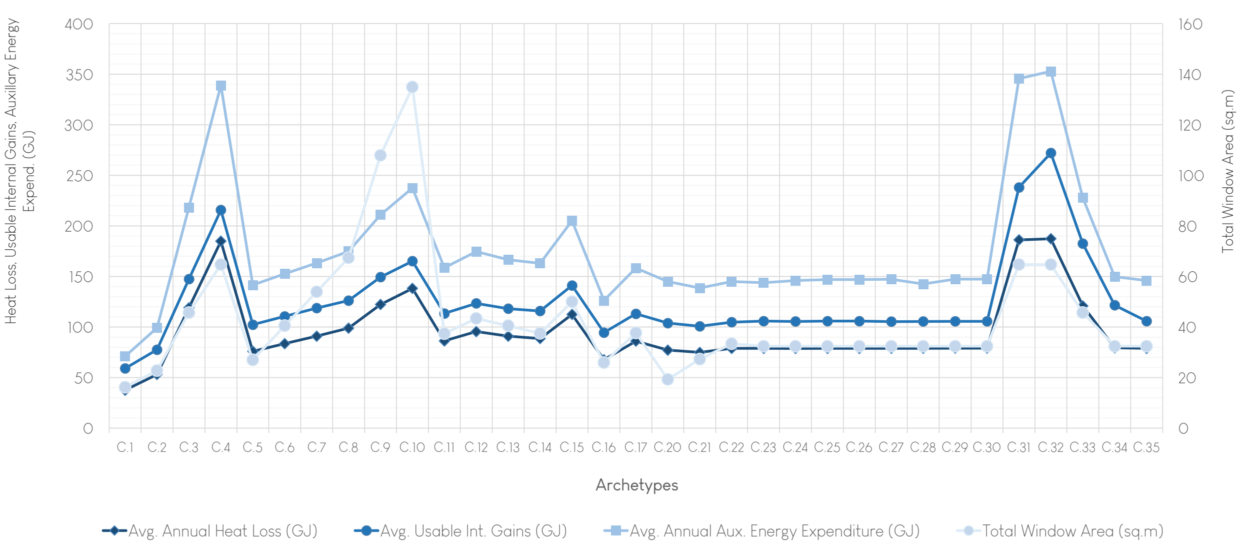
This section focused on the size of a home in floor area, envelope surface area, window area, foundation type and building shape and how each related to the efficiency of the building in the primary metrics of MEUI and TEDI. As with the last section, surface area arguably plays one of the largest roles in determining the efficiency of a home. The higher the external envelope surface area, the more opportunity for heat loss between outdoor and indoor environments to occur (as heat energy wants to move from high energy (warmer) to lower energy (cooler) spaces to equalize.

When comparing home volume to surface areas, it was noticed that the smallest home in the study, Case 1, is the least efficient in regards to its relative MEUI and TEDI. If you look at the largest archetypes in the study, Case 4, 31 and 32, each has the best proportional relativity between MEUI, TEDI compared to Volume to External Surface Area. While volume increases in a shape, its relative surface area drops. As such, the most efficient homes will be those that combine multiple units into a single, larger floor area building. This is also true in shape, where the lower the surface area, the more efficient (some consideration needs to be placed on the microclimates different shapes create). So while the appeal for living in smaller homes may be a good one based off how it may influence the way in which the occupant behaves and the fact that these smaller homes generally consume far less energy, it can also amount to more inefficient buildings if implemented as many small, individual homes on independent foundations and plots, increasing the embodied energy in construction and the potential losses through poor volume to surface area ratios.

This change in volume and area is applicable to windows, given that the window unit is often less insulated than a wall assembly and forms a path of least resistance for heat to escape the building in an attempt to equalize with its surrounding environment. When a home has a larger or smaller window area, its relative energy metrics adjust almost perfectly with its curve (Fig.2)

This is also seen in foundations, where a larger foundation or basement provides more surface area from where energy can move between the outdoor and indoor environment if proper wall assem-bly insulation is not present.

Figure 2. **Total Window Area and the Effect on Energy Expenditure.**



Summary

Local Climate and Overall Efficiency

This section focused on the impacts of different climate zones and conditions on the efficiency of a home, and how elements such as airtightness (ACH), window area and distribution, among other passive measures.

Normally we associate higher insulation levels with colder climates, but insulation has the same effect in warmer climates - if you have a sealed interior from where a consistent comfortable temperature is needed, insulation acts as the material that slows the movement of heat from a hotter area to a cooler one, which makes it great for keeping heat in or out of a building depending on the climatic context. This data saw trends that followed this logic, the least efficient homes were those that were not sealed or well insulated, the most efficient were those that were sealed and well insulated. All variables in the most and least efficient for each case in each climate zone were equal.

Airtightness (ACH) in this study was a measure of how 'sealed' a home was. If the building had a lower ACH value it exchanged its used air less often, resulting in lower energy costs to temper the air. What was found was that the severity of heat loss is directly related to the local climate of the region the home is in. The relative impact that ACH has on TEDI does not seem to change much between climate zones, with thermal demand rising significantly if there happens to be an air leak or an over-exchange of air in ventilation. Every other area noted here, MEUI, Utility Costs, and Heat Loss, are all affected to a much greater extent in regions with more extreme temperature differences between indoor and outdoor, with Fort Nelson (CZ 7b), the Northernmost city in the study, reporting these higher comparative differences (table below).

Figure 3 - Relative impacts of different ACH Values in different Climate Zones

Vancouver
CZ 4

	1.0 ACH Value	2.5 ACH Value	3.5 ACH Value
Avg. Annual MEUI (kWh/sq.m)	44.4	47.6	49.8
Avg. Annual TEDI (kWh/sq.m)	16.9	20.5	22.9
Median Annual Utility ($)	1419	1466	1500
Avg. Annual Heat Loss (GJ)	46.9	50.4	52.8

Percentage Difference (1.0-2.5)	Percentage Difference (2.5-3.5)
7%	5%
21%	12%
3%	2%
7%	5%

darker colour = larger change

Fort Nelson
CZ 7b

	1.0 ACH Value	2.5 ACH Value	3.5 ACH Value
Avg. Annual MEUI (kWh/sq.m)	102.8	117.4	127.4
Avg. Annual TEDI (kWh/sq.m)	72.5	87.4	97.5
Median Annual Utility ($)	2329	2557	2712
Avg. Annual Heat Loss (GJ)	99.9	112.6	121

Percentage Difference (1.0-2.5)	Percentage Difference (2.5-3.5)
14%	9%
21%	12%
10%	6%
13%	7%

darker colour = larger change

Summary

Local Climate and Overall Efficiency (2)

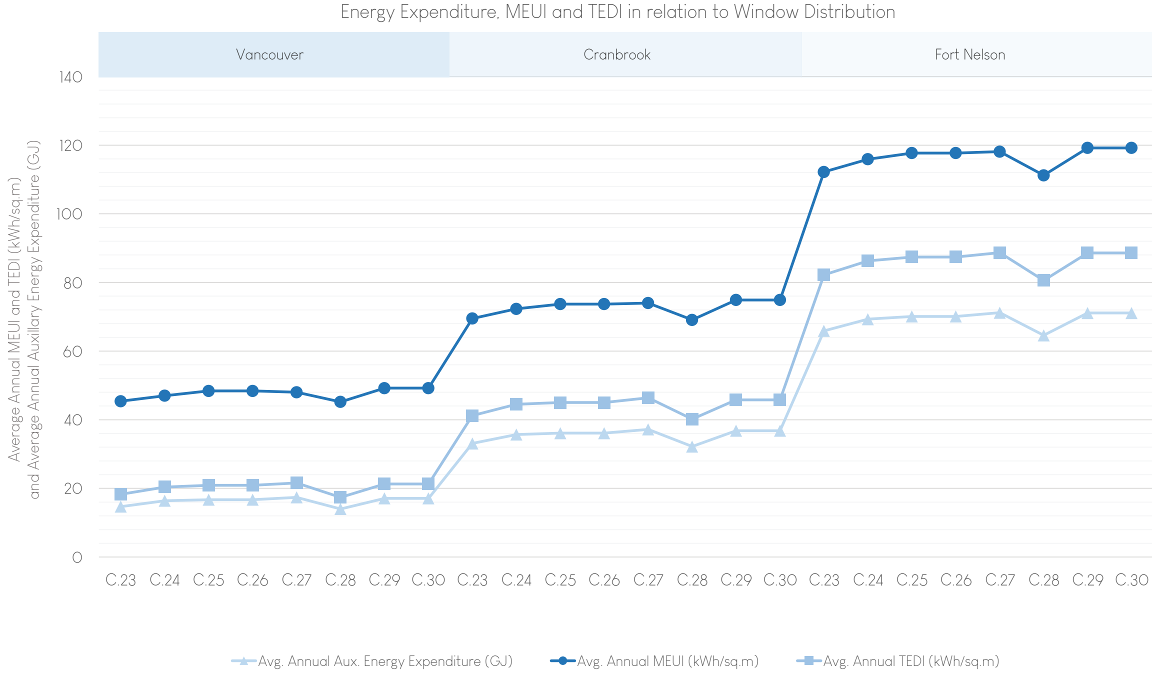
While window distribution will have an effect on the efficiency of windows given certain facades receive more or less sun exposure, the single largest determinant in the efficiency of a home barring the wall assembly is the overall window area. Think of windows as an efficient opening, it may be more efficient than an open door, but it still provides the path by which most heat will escape a building should the assemblies be well insulated enough and there are no leakages. Utility costs in this case constantly rise from the mild Vancouver climate to the cooler Fort Nelson climate. As such, it was seen that even the most conservative amount of windows in Cranbrook (10% WWR) was barely more efficient than the most windows (50% WWR) in Vancouver – and the same for Fort Nelson. So while views may be important to the experience of a home, conservative gestures will ensure greater architectural efficiency regardless of climate.

While less determinant, a window layout that favours distribution on faces that have reliable sun exposure – the South primarily, will inevitably be more efficient than those that favour the cooler Northern face of a building in our hemisphere (Fig. 4). As seen in the Figure, all metrics are affected in similar manners in their specific distribution, though the South centric distribution of Case 28 remains the most efficient.

Figure 4 – Window Distribution and its Effects

	C.23	C.24	C.25	C.26	C.27	C.28	C.29	C.30
Window Distribution on North	0.3	0.5	0.1	0.1	0.65	0.25	0.05	0.05
Window Distribution on East	0.1	0.1	0.5	0.3	0.05	0.05	0.65	0.25
Window Distribution on South	0.5	0.3	0.1	0.1	0.25	0.65	0.05	0.05
Window Distribution on West	0.1	0.1	0.3	0.5	0.05	0.05	0.25	0.65
Total Area-Windows-m2	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4

Energy Expenditure, MEUI and TEDI in relation to Window Distribution



Conclusions

As we move ever closer to achieving the net zero ready buildings referenced by the BC Step Code for 2032, it will become more and more important for the occupants of the building itself to have an active role in promoting the efficient use of energy inside the home. This report has tried to break down some of the initial hurdles in background understanding to provide a baseline level of understanding from where homeowners and builders can communicate and participate the architectural design conditions that will have an effect on the efficiency of a building through its lifecycle.

It is important that this information continues to be broadcasted in a digestible manner for each level of the design, build and end-use stages of a building - and this becomes more important as the technology associated with some of these homes becomes more complex, advanced and potentially hidden within our homes. With most of a buildings energy being consumed in the operational occupant stages, providing the opportunity to shape both the understanding and the behaviour of the occupant becomes of greater concern in taking the next step towards truly efficient architecture in our cities.