4. CD-1 Rezoning: 1477 West Broadway

Date Received	Time Created	Subject	Position	Content	Name	Organization	Contact Info	Neighbourhood	Attachment
04/12/2022	11:11	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	I vehemently oppose this building due to its height and massing. NONE of the objectives the City wants will be achieved. For example, it will not lower rental costs & in fact, it will increase them (if you believe otherwise, please ask for the data that CLEARLY shows exactly what happens to the rents amounts each time a property has been rezoned to a high rise tower); it will not help lower or middle class residents to rent affordable housing; in no way will it increase the income of lower or middle class residents to help rent or buy housing; it will continue to set an awful precedent for the destructive "tower" build form; the use of concrete is not environmentally friendly; it will PERMANENTLY SHADE THE AREA SOUTH of the building for ETERNITY; it is architecturally outlier for the community area; the building is being approved BEFORE the Broadway Plan has been approved, which is wrong; it is penalizing city taxpayers by subsidizing developers; there is little to no infrastructure in place for schools and parks to support the growth this tower will bring; the intentional lack of public consultation on this building rezoning was practically non-existent ' therefore it implies resident's voices are worthless. Every one of these points has REPEATEDLY been communicated to City Planners and Council for many years. None of these items are new nor surprising. But what is surprising is the consistent, constant, & complete indignation shown to both local area residents and City of Vancouver residents as a whole through the rezoning (& other) planning and consultation process.	Kathy Hochachka		s.22(1) Personal and Confidential [redacted]	Kitsilano	No web attachments.
04/12/2022	11 53	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	While densification is nice to have around skytrain stations, 39 stories seems excessive and will look out of place, and will block the view along Broadway. t will be a shame in the future for the city to become a concrete jungle	Jeffrey Lane			Unknown	No web attachments.
04/12/2022	12 26	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	I am opposed to the proposed rezoning of 1477 West Broadway based on the application before Council. My reasons are outlined in the attached letter.	Stephen Mikicich			Kitsilano	Appendix A
04/12/2022	12 59	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	While I would support the revitalization of Broadway, I am not in favour of high rises. I do not believe Vancouver needs another downtown (Uptown). Please keep highrises to the West End!	Randy Kondo			Kitsilano	No web attachments.
04/12/2022	15:11	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	More consultation with the community and more acceptable height, say 25 stories. Is there a community plan you are following'	Russell Wolansky			West Point Grey	No web attachments.
04/12/2022	15 34	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	I am a Vancouver resident who opposes the 1477 West Broadway proposal. I do not live in the immediate vicinity of this proposal, but worked there for many years, so know the area well. I oppose the tower firstly because I believe it is too tall for the area, causing many problems that will not be balanced out because of its so-called benefits. The impact of its shadows has not been properly assessed or considered in this proposal. Researchers are now finding that towers like this are environmentally unfriendly because of the greenhouse gas emissions required to build them, live in them, and finally to tear them down, as they have a relatively short lifespan. If the city is truly concerned about climate change, it should be looking at the many alternative ways of increasing density that do not involve 39-storey concrete towers. The argument that this tower will produce affordable housing seems weak given that most of it will not in fact be affordable, nor will it be suitable for families. t is not ground-oriented housing, and parks and schools with capacity for more students are not immediately accessible. The small amount of below-market rental the tower will provide does not justify its significant negative impacts on the neighbourhood. Perhaps most worrisome is the murky, non-transparent process that has seen the proposal get to this point. Community residents were not properly consulted, and they have described being stalled and misled when they tried to get information about plans for this site. Approving a rezoning based on an as-yet-unapproved Broadway Plan does not instill confidence that the City is listening to the public. Please reject this proposal.	Carol Volkart			Dunbar-Southlands	No web attachments.

Date Received	Time Created	Subject	Position	Content	Name	Organization	Contact Info	Neighbourhood	Attachment
04/12/2022	16 31	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	Regretfully, I must oppose the approval of this rezoning. It is as though there were a plot afoot to foist darkness on the public, so the sun won't shine on the places where people need it the most. t is even worse that this plot is not necessarily deliberate. To secure 46 residential suites at below market rates the City is being asked to encourage the demolition of many more existing affordable homes. That is the knock-on effect of selling height in this type of vertical safety deposit box. Context is more than a charming echo of warm colours, cornices and textured patterns. The perfunctory shadow studies do not portray show the full shade cast by this building. They do show that 7th Avenue, two blocks downhill, will be substantially in shadow from September to March. t is in those months that solar access is of maximum importance for the wellbeing of the public realm, and residents in the yet to be demolished apartments. This proposal started as a good idea, but now breaks the limits of valid rationale for the public interest. This site was long limited to less than 100ft in height for the good reason of assuring benign impact on the life experienced downhill. The imperatives of excellence could take this a little past 200 feet with careful sculpting of its impact on its northern shadow path. But what is in front of you is purely about money, not about suitability. The development industry responds to the lack of constraint with unbounded appetite for leveraging profit. t uses the rhetoric of Metrocore Jobs and other growth strategies as trojan horses to worm through the city's walls. I know this, I have been there, done that. But there was a very rigorous urban design process to satisfy. Financial success is to be encouraged but not the sacrifice of the quality of the Commonwealth. Council must take a stand on behalf of the kind of city its own City-wide plan is suggesting. Naive numbers chasing has caused city staff to allow this development to balloon to a monstrous scale. But this ignorance does not lead to bliss. Rather the opposite, once in motion a steamroller is hard to halt. This rezoning will lead to the early demise of large amounts of housing in the Broadway corridor. The City may have a lack of bandwidth in managing the totality of impacts and opportunities. But this is not a reason, nor the time, to throw away the fine fundamentals that underlie the Broadway plan. Ratcheting up building bulk, as though the downstream impact on other people doesn't matter, should not be condoned by Council. The planners talk about shaping the city. Don't be fooled, this is not sculpting. Once the Denny's site slipped through the gate, this doubling of height has immediately become the new baseline for every developer along Broadway. Reasonableness was a hallmark of Vancouver's urban transformation. Don't be bullied. Prove that you are reasonable people and insist upon a scaled back version of this Rezoning proposal.	Graham McGarva		s.22(1) Personal and Confidential [redacted]	Fairview	Appendix B
04/12/2022	18:45	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	The building of high rises is in conflict with the City's Climate Change Adaptation Strategy and also in conflict with the City's Zero Emissions Building Plan. Buildings are directly responsible for nearly 40% of all greenhouse gas emissions according to the International Energy Agency. A Chicago study look at 2,000 units and where they were sustainable in an unbiased way. They found out that the four-story courtyard uses the least energy per household. One other study conducted in the UK found that high rises of 10 stories and higher used 76% more electricity per sq-ft than buildings with five or less stories. various peer-reviewed studies indicate that large buildings such as the one being planned at 1477 W Broadway account for more emissions than their smaller counterparts. Another study, recently published in Urban Sustainability, a Nature publication, suggests that there is a growing belief that building taller and denser is better. However, urban environmental design often neglects life cycle GHG emissions. The results presented in the paper show that taller urban environments signi'cantly increase life cycle GHG emissions (+154%) and low-density urban environments signi'cantly increase land use (+142%). However, increasing urban density without increasing urban height reduces life cycle GHG emissions while maximizing the population capacity. There seems to be growing evidence that building high rises is NOT the most efficient way to meet growing demand for urban space and that if the City is serious about addressing the climate change emergency, it should not approve the building of high rises at this location and other locations that are part of the Broadway Plan. The idea that the use of "green" concrete will reduce emissions at any significant level is not completely accurate. Concrete is the number one source of embodied carbon in buildings ' accounting for up to 55%. And it is responsible for 8 to 11% of global CO2 emissions. CarbonCure Technologies has a process that takes some CO2 out of the air and incorporates it into the concrete, which strengthens it, reducing the amount of cement needed. So far, CarbonCure concrete achieves a net carbon reduction of only 5 to 7%. Lehigh and Lafarge, are blending cement with materials such as dried biosolids from wastewater treatment. Lafarge's EcoPact, has a carbon footprint between 30% and 40% lower than the current industry average. Since the cement component creates 80% of the CO2 emissions of concrete, the reduction in concrete's CO2 emissions is between 24% and 32%. Since the construction stage contributes 9% to 35% of the lifecycle GHG emissions, these reductions would only reduce total high-rise emissions by 2% - 11%. These reductions are even less impressive when one considers that taller urban environments increase lifecycle GHG emission by +154% (two and a half times). I hope Councilors understand the severity of the climate change emergency and oppose this project.	Jos? R. Bicudo		[redacted]	Fairview	Appendix C
04/12/2022	19:45	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	Not the original plan approved by city; the building is already under construction. Also the height is too high for the neighbourhood.	Laura Rock		[redacted]	Fairview	No web attachments.

Date Received	Time Created	Subject	Position	Content	Name	Organization	Contact Info	Neighbourhood	Attachment
04/12/2022	20 55	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	I have lived in Vancouver my whole life - on the West and East side; in houses, rental apartments, duplex and a condo a block away from 1477 West Broadway. I strongly urge you to vote against this rezoning. I have numerous concerns but will limit my comments to a few key items. Firstly, this rezoning is premature. While I appreciate Translink's concern about impact on the station if this property is later zoned, the reality is that a rezoning now to allow 39 storeys will lock us into a Broadway plan that has not yet had appropriate opportunity to be considered, nor full public consultation. This is not about 1 tower, it is part of a plan to transform a number of neighbourhoods. If you approve this now, you are taking an inappropriate and premature step in expectation of a broader plan that has not been fully considered and vetted. This is unjust and unfair. Secondly not enough consultation has occurred, even on a stand alone basis for this one huge tower. I had no idea that a 39 storey was being considered until I (unlikely many who will be impacted) received a 'postcard' dated March 29 to announce this unwelcome news. I pay attention to what is going on in my neighbourhood, and had made inquiries when the construction was started and satisfied myself with the approved plan of the skytrain station and a 5 storey office building on this site. From the recent inquiries I have made, I believe that most Vancouverites, including those who live in the immediately neighbourhood, still believe that this is what will be constructed. During a pandemic, communication and participation are at a huge low - the City must do more to engage its citizens in a hugely transformative change like this. Anything less is contrary to your mandate. Thirdly, and most importantly, a 39 storey tower is an inhuman and unwanted monstrosity. It will not make a meaningful impact on the housing crisis - the entire 'Broadway plan' to build a few huge towers near the location of what will be a few sparsely located skytrain stations with 20% below market housing along a narrow strip is misguided at best. You want to make a 'great street' or build a vibrant city filled with diversity, community interaction and vibe' Think along the lines of Paris - fill all neighbourhoods with density on a human scale: 5 storey buildings and mixed use everywhere. Even look at Olympic Village for the blue print. Go take a look at Broadway and Granville - it sits like a Crown on a very special ridge. The neighbourhood is one that could be a model for others in Vancouver - continue to build 10-15 storey residential or office/mixed use towers and in-fill on non-main streets with 3-5 storey residential buildings. This will continue to encourage a community that people will want to live and work in. Not a commuter based, get me out of here as fast you can, cold and inhuman strip of towers - or even just one tower - that are beyond what makes sense in this neighbourhood. Please vote against this.	Catherine Gibson		s.22(1) Personal and Confidential	Fairview	No web attachments.
04/12/2022	21 55	PH2 - 4. CD-1 Rezoning: 1477	Oppose	I oppose this rezoning. Please read the details in my attached document.	Ian Poole			Fairview	Appendix D
04/12/2022	22:40	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	Please refer to the attached letter opposing this application.	Ian Crook			Unknown	Appendix E
04/12/2022	23:40	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	No online public open house was held. Makes a farce of the yet-unapproved Broadway Plan, and it sets an unfortunate precedent for the whole Broadway Corridor. The developer is attempting to sidestep $3 3M in fees and will not make any financial Community Amenity Contributions (the money used for childcare facilities, social housing, and parks). Why does the City give away so much (in terms of height, density and cash) and ask so little in return, while developers continue to make such obscene amounts on these developments' Staff say that no public parks or plazas are shaded by the building, but they didn't assess shadowing at the winter solstice, the darkest time of the year when the shadows are longest.	Tandy Wallace			Kitsilano	No web attachments.
04/13/2022	02 31	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	I have lived in Vancouver for over 45 years, and, like many other residents, I take pride in and enjoy its city scape that adapts to its natural beauty and is oriented to human scale. The proposed 40-story tower is so much against Vancouver's characteristics, and it would set a precedent for the entire Broadway Corridor ahead of the Broadway Plan. It would lead to our city becoming an inhumane metropolis.	Aiko Osugi			West Point Grey	No web attachments.
04/13/2022	08 03	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	I have lived in Vancouver since 1971. I have been employed by the City from 1971 to 1974. More recently I have been employed by the Province of BC. I strongly oppose the construction of this high rise building.	William Kerr Clark, Q.C.			Fairview	No web attachments.
04/13/2022	09 06	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	I oppose the 39 storey building at Granville. The land is extraordinarily high there making this equivalent to a 50 story building which will drastically shadow the public realm, Fairview and critical shared amenities. The existing Broadway guidelines warn against too much height on Broadway Ridge shadowing downslopes - height is to be further south at 16th. There are insufficient school and other services for this level of density in conjunction with other planned density plus that corner is too noisy for residential. Density should be spread equitably thru ALL of Vancouver to avoid super-concentration like this. The height was set outside of theBroadway Plan engagement, which is unacceptable. The Vancouver Plan is already showing a pushback against tower forms and work from home is changing locational requirements. Livability is being sacrificed 1 building at a time without considering the collective impact nor the Broadway themes which highly valued access to sunlight. We do NOT have a height crisis and this density could be achieved within existing zoning and moderate forms.	Anne Creaser			Fairview	No web attachments.
04/13/2022	09:44	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	I am against this monstrosity of a tower in the area I call home. If I wanted to live downtown I would have moved there. Keep high rises OUT! STRONGLY OPPOSE	Brandon keda			Fairview	No web attachments.
04/13/2022	09 56	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	This proposed 39 story tower is completely out of character with the surrounding area. It is TOO HIGH. I am also concerned about the entire "Broadway Plan" which includes similar towers along Broadway. In my opinion the city should be limiting tower height is the Broadway corridor to 15 stories which would already be higher than most buildings in the area. The city is on a trajectory to destroy the character of our city by approving these gigantic buildings. We have enough of them downtown and in the West End already.	Kathryn Shaw			Kitsilano	No web attachments.

Date Received	Time Created	Subject	Position	Content	Name	Organization	Contact Info	Neighbourhood	Attachment
04/13/2022	10 01	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	This project will harm affordability. Distributed density in low and mid-rise has the potential to improve affordability and can be sustainable. This proposal is environmentally damaging - concrete high-rise construction has huge embedded greenhouse gas impact. Further, the shadowing will leave areas to the north in a winter darkness.	Craig Ollenberger		s.22(1) Personal and Confidential	Unknown	No web attachments.
04/13/2022	10 03	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	Vancouver City has an established View Corridor policy. This 39 storey building goes against the View Corridor policy, impacting views of the mountains that Vancouver is known for. Also the redulting shading will impact the outdoor space used by residents, decreasing their enjoyment of the outdoors.	katherine reichert			Shaughnessy	No web attachments.
04/13/2022	10:13	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	Vancouver had an established View Corridor policy. This 39 storey building goes against this View Corridor policy, greatly impacting views of the mountain which Vancouver is known for. The resulting shading will impact livability of the residents living north and west of the tower.	katherine reichert			Shaughnessy	No web attachments.
04/13/2022	10 58	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	This is a massive, precedent-setting increase in allowable density that will result in continued increases in land value, as has happened in every other rezoning of this type (Cambie, Brenhill, West End, etc.). The result will be _decreased_ affordability -- there's no way to build affordable housing on unaffordable land. Look at the Brenhill building at Helmcken & Richards St. downtown. t was billed as providing "affordable" housing. It sits 80% vacant -- both the "social" housing and the condos -- because the costs are way out of line with what residents can afford. Don't repeat this mistake yet again! We desperately need more _affordable_ housing, not condos and rentals that the people who live here can't afford.	Alan Albert			Downtown	No web attachments.
04/13/2022	11 00	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	This city should not be another Asian city with tall towers - the proposal is too tall.	Louise Ries			West Point Grey	No web attachments.
04/13/2022	12:18	PH2 - 4. CD-1 Rezoning: 1477 West Broadway	Oppose	Do not want 39 plus stories buildings Keep them in west end downtown only You cannot get out if fire for first responders Too much sun on all glass skins Glass. t good at keeping excessive heat out Not sustainable like lower rises Studies prove isolation studies show the higher the building the more negative impact on persons health New York high rise dwellers complain re lack of light Studies show survival for cardiac arrest greater on lower floors than higher floors there were no survivors above the 25th floor. Lower response times Vancouver ties do not want Hong g Kong buildings think of vancouver 50 years ago you are ruining our city and citizens health with these developer wmo et changes	Donna Barker			Fairview	No web attachments.
04/13/2022	13 29	1477 West Broadway	Oppose	Council needs to oppose the CD-1 Rezoning: 1477 West Broadway. We live in Burrard Slopes and rezoning this building from 5 to 39 stories will set a precedent that destroys the entire neighbourhood. This is clearly for the benefit of the developers and not for the residents and businesses who have helped to built Vancouver into the vibrant city that it is today.	Hilary Bookham			Fairview	No web attachments.
04/13/2022	13 39	1477 West Broadway	Oppose	I own a condo along the corridor and stand to profit from large expansion models like this. However, affordability and inclusion are FAR more important than making a couple of bucks. Please stop the 40 story tower from being built along the Broadway Corridor. Demand that any and all investors use some of their profits to build accessible housing, park space etc for the rest of those who can't afford these crazy high prices.	Niky Clarke			Grandview-Woodland	No web attachments.

April 12, 2022

Mayor and Council
City of Vancouver
453 W 12th Avenue
Vancouver BC V5Y 1V4

RE: PROPOSED REZONING OF 1477 WEST BROADWAY

Your Worship and Members of Council,

The City of Vancouver is requesting public feedback on a rezoning application at 1477 West Broadway. According to the City's website, the proposed rezoning from C3A to CD-1 would provide for development of a 39-storey, mixed-use building above the South Granville SkyTrain Station, including:

- 223 rental residential units, 20% at below market rates
- Commercial retail space on the first and second storeys, including a grocery store
- 5-storeys of office space within the podium
- A floor space ratio (FSR) of 12.16
- A building height of 125 metres (410 feet)

I provide the following comments for Council's consideration:

1. This public hearing is an opportunity for Council to hear public feedback on the proposed rezoning of 1477 West Broadway. However, this could be the last opportunity for the public to comment on any future rezoning within the Broadway corridor:

    - Josie Osborne, former Minister of Municipal Affairs is quoted in an October 2021 news release from the Province as saying: *"We are working with local governments, the development sector and housing advocates to streamline local development processes to help get more homes built faster for people."* Notably absent from those discussions are existing residents.

    - The subsequent amendment to the Local Government Act **has removed the default requirement for local governments to hold public hearings for zoning bylaw amendments that are consistent with an official community plan**. It is my understanding that Council will be considering approval of the draft Broadway Plan in May, while the public will have only a few weeks to review, understand, and comment on the Plan and its implications.

2. The development proposal for 1477 West Broadway represents a collaboration between the developer, the Province of BC, and the City of Vancouver to advance construction of the Granville subway station and to secure a desired housing mix on this site. With that in mind, how amenable is the City to addressing public concerns about this project – given that excavation work on the station site and building foundations is currently underway?

3. It is noted in the staff report that the developer will not be required to provide a Community Amenity Contribution (CAC) and will be receiving a significant waiver of Development Cost Levies (DCLs) as development incentives, while permitted density will increase four-fold:

- It is important that local governments recognize the relationship between CACs and housing affordability; and make efforts to balance the opportunity to obtain public benefits, such as community amenities, with the goal of helping people to secure "affordable" housing.
- In this case, only 20% of residential units would be offered at below market rates, while the market units will demand premium rents due to the potential views from this site. I do not see the project contributing to public spaces or facilities to meet a range of social, cultural, recreational, and infrastructure needs of the community (i.e., community amenities).

4. From a built form perspective, a building of 39-storeys it too tall for this location (i.e., at the top of a hill above the False Creek basin) and is very much out of scale with South Granville and the surrounding Fairview neighbourhood.
5. The rationale provided for considering this rezoning in advance of the Broadway Plan is that it could expedite construction of the South Granville Station by six months. By allowing for consideration of this proposal and two other tall buildings (one at Hemlock, the other at Birch) in advance of the Broadway Plan, Council has clearly set a development precedent for the entire Broadway corridor, which is confirmed by the recently released Plan.
   - This is quite concerning from a process perspective because it could taint the whole Broadway Plan as a pre-determined outcome.
   - Based on my conversations with local area tenants, homeowners, business owners, and service workers who live or work in the Broadway Plan area, it is clearly apparent that public awareness of this transformational plan is very limited. I would ask that Council reconsider the stated timelines for formal consideration of the Broadway Plan and the just released City-Wide Plan to allow the public more time to understand these complex documents, and to provide meaningful input.
6. While the policy directions the City is pursuing are focussed on increasing housing supply along the Broadway corridor, I am already hearing of pending displacement of existing tenants of purpose-built rental buildings. Similarly, homeowners are concerned about being able to stay in their homes as assessments and property taxes increase based on future land use designations and redevelopment pressures. I provide this sampling of the discussions I have been having:
   - My hairstylist is a young woman living in a well-maintained 40-year-old rental building in Fairview. She noticed that her landlord recently stopped making typical investments in routine building maintenance and upgrades. He told her, "why should I bother when the building will be coming down in a couple of years?" She is asking "where will I go?"
   - A Kitsilano resident who owns a modest bungalow with a secondary suite occupied by a young family asked me "how long do I have before they want to tear my house down?"
   - In Arbutus Walk, a master-planned multi-family community (rental, ownership, family co-op, and seniors' housing) in Kitsilano, residents are coming to realize that the draft Broadway Plan designates their neighbourhood for 20-30 storey towers. The oldest buildings are barely 20 years old. I asked City staff why this model community would be targeted for redevelopment

and was told that the “CD sites would be left alone.” So, does that mean that the well-used public open spaces would be replaced with towers?

7. While we all agree that we need more varied housing options and the right kind of supply, Council must understand that existing Vancouver residents, both tenants and homeowners, are not the obstacle to achieving this:

   - A decade of rhetoric has been demonizing existing residents as “NIMBYs” and putting the blame for housing unaffordability on “mansion zoning” and lower density “legacy neighbourhoods.” In reality, there is no single-family zoning in Vancouver as virtually every lot can be developed with three housing units outright.

   - At the same time, the impacts of foreign investment on the local housing market are now grudgingly acknowledged by government and the development sector, both of which had been actively promoting it for years. Today, the new wave of redevelopment frenzy and price escalations in Vancouver appears to be fueled by large scale institutional investors entering the local real estate market.

8. I am fearful that the blind focus on housing “supply” is justification for silencing residents’ voices and enabling the potential ‘clear-cutting’ of an entire city:

   - During the urban renewal era of the 1950s and 1960s, Vancouver residents had to rise-up against ‘top-down’ planning by local technocrats and senior government agencies set on ‘slum’ clearance, resident displacement, and freeway development. Today, it seems that much of the city is being portrayed in the same light, except this time we need to make room for a subway and ubiquitous 40-storey towers.

9. True “Vancouverism” is not about towers built over street-friendly podiums; rather, it is a livable city built upon meaningful community engagement and active citizen participation in the planning process.

I thank you for the opportunity to provide my comments and trust you will give them your thoughtful consideration.

Sincerely,

s.22(1) Personal and Confidential

[redacted]

Stephen Mikicich, RPP, MCIP

s.22(1) Personal and
C fid ti l

[redacted]

Council context / Counsel context

Context is everything. Not what it is, but the fine grain of what matters, the small stuff you need to sweat. The being next door, or across the street, or feel of welcome as you pass a new doorway. This is difficult when you are not that you, when yours is not that daily footstep anxiously wondering whether the new doorways will open with greeting, or if the windows will warm to you.

> For you who are the real estate mover, shaker, architect, lobbyist of the front door back door; your context is elsewhere. You've got your own office, journey to work, your family or facsimile. This is not you - you've got your own small stuff, from which this multimillion-dollar behemoth is a release valve, a tap from which much of your prevailing pressure escapes -

sad but true.

I used to be you.

I know your context,

I know where structure meets the ground the ground is difficult; its setbacks and slight slopes stumbling blocks to the pure delineation of virtual lines, a messy place, not something to get stuck on, this matter of up close and personal that clutters the priorities of the pro forma, with its pigeon holed budget for design; limited.

Context is that obligation beyond legal boundary,

seeps across property lines.

often seen as disconnected if seen at all, just a strip of contact prints assembled by the office junior. Condemned to be seen as in the way of the high priced help getting the permit at hand. Reflection is seen by the mover as a mirror of mounting interest as measured by the bank. This is accounted unacceptable.

Thus short term financing presses to outweigh long term public interest, and this lack of reflection adds to debt payable by the decades to come. The accountants tell that this does not matter. Life is common property, a vapour squeezed through the living breath of everyone; and everyone doesn't count; being off book. STAND UP BE COUNTED.

Context is everything, it holds the key that unlocks the door into the rose garden. There we citizens try to live together. And without this, we are homeless.

CTBUH Research Paper

Title: **The Environmental Impact of Tall vs Small: A Comparative Study**

Authors: Christopher Drew, Adrian Smith + Gordon Gill Architecture
Katrina Fernandez Nova, Adrian Smith + Gordon Gill Architecture
Keara Fanning, Adrian Smith + Gordon Gill Architecture

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The Environmental Impact of Tall vs Small: A Comparative Study

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Adrian Smith + Gordon Gill Architecture, 111 West Monroe Street, Suite 2300, Chicago, Illinois 60603, USA

Abstract

The concept of vertical living has been hailed as a solution to control fast growth and urbanization of cities worldwide. As super tall residential projects become more common and sustainability considerations become more necessary, their efficiency has been called into question. How do vertical residential developments compare with suburban homes? What are the environmental advantages and disadvantages of vertical communities? Is there a middle ground?
We present the results from an AS+GG study that compares the environmental performance of different housing typologies ranging from a 215 supertall building to single family residences, including several scales in between. Our samples comprise 2,000 residential units per type and include the infrastructure needed to support them. We analyzed land use, energy use, and lifecycle carbon emissions for each typology.
The results show that different typologies perform better depending on the parameter being assessed. We discuss these findings; assess overall performance, and present conclusions.

Keywords: Supertall, Energy, Land, Urban sprawl, lifecycle carbon

1. Introduction

At the beginning of 2014, the global population stood at over 7.1 billion people (USCB, 2014). The United Nations estimates that the global population will exceed 8 billion by 2025 and almost 11 billion by the turn of the next century (see Fig. 1). This will be accompanied by an increase in overall average population density from 51 people per sq. km in 2010 to 60 in 2025 and 147 by 2100 (UN, 2014a).

Urbanization, which is the growth or expansion of urban areas, has recently become the focus of a great deal of attention. In 2010, the global urban population exceeded 50% of the world's population, by 2025 it will reach 58% and by 2050 it will exceed 67% (UN, 2014b). In 1950, when the world's population was a mere 2.5 billion there were 83 cities with over a million people (compared to 12 in 1900). This number has risen to a present day total of more than 520, with 30 cities having more than 10 million and 12 having more than 20 million inhabitants (Brinkhoff, 2014). These staggering numbers are prompting planners and policy-makers alike to ask questions about the sustainability of city growth and try to understand how best it can be planned.

Urbanization occurs as a result of two processes - migration from rural areas and natural population growth. Migration from rural areas may occur as a result of a number of factors. Mechanization of agriculture means that fewer farm laborers are required and therefore there are fewer opportunities for employment on farms and in other agriculture related industries, forcing people to seek employment in urban areas (this phenomenon is known as rural flight). Often, people move to the cities simply for the economic benefits and career opportunities. Furthermore cities tend to have a greater range of education options for parents to choose from for their children as well as better healthcare and social facilities.

There are, however, some negative environmental effects associated with urbanization, the most prevalent known as urban sprawl. Sprawl is a complex socio-economic phenomenon, but one of its defining characteristics is an imbalance between the physical form of a city and the desires and needs of its population. These desires may include specific housing types, neighborhood structure, and the provision of services and/or available recreation space. Consequently, when a population cannot meet all of its needs in one location, it will migrate to other areas to meet those missing needs.

The concept of high density vertical living has been hailed as a solution to control the fast growth and urbanization of cities around the world. As supertall residential projects become more common and sustainability is regarded as a pressing issue for the built environment, the efficiency of such projects is often called into question. How efficient are supertall residential developments versus low-rise single-family residences? What are the environmental, social and economic benefits and/or disadvantages of vertical communities? Is there a middle ground?

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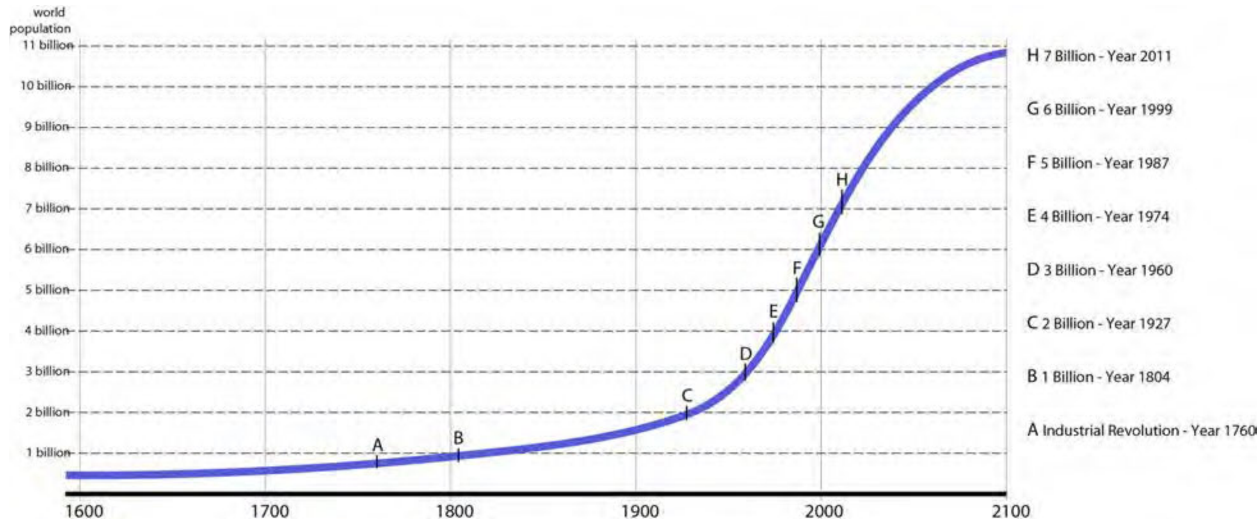


Figure 1. World population growth (Source: UN data).

This study was undertaken in order to compare the environmental performance of different urban and suburban residential building typologies ranging from supertall buildings graduating down to single-family residences. In all, nine different buildings were designed, divided into four broad categories based on their height and nature: supertall, high-rise, low-rise and single family homes.

Each typology was analyzed against a series of environmental indicators - land use, energy demand, transportation and life cycle carbon emissions.

2. Methods

2.1. Building Typologies

As described above, nine residential buildings were designed within 4 categories as described above. Each was designed for an ASHRAE climate zone 5 (such as Chicago) and was tested for constructability and compliance with Chicago's Building Code and ASHRAE 90.1 (2010). Each typology was designed using typical building materials and mechanical systems to allow for a better comparison of the different models.

The sample size for the study of each typology was 2,000 residential units, including the infrastructure needed to support them, creating nine hypothetical communities (see Fig. 2). The housing was designed following two distinct approaches: firstly, a market based unit size (based on a cross section of apartment and house sizes within the Chicago area), which was termed Tbase and secondly on a fixed unit size of 150 m^2, termed T150 (see Table 1). The two approaches allowed us to make relative comparisons of total energy demand (using Tbase) and energy use intensity (using T150).

2.2. Energy Use

Energy Models were constructed using Design Builder and run in Energy Plus for all the prototypes in the Density Study. This allowed the estimation of overall energy consumption as well as demand profiling for each typology. Buildings were modeled as part of prototype communities, to take into account the effect of overshadowing by neighboring structures, as would be in real life. To eliminate the influence of orientation, the energy models for each prototype were run in four cardinal directions with the mean result being considered for the discussions. These individual results were then extrapolated to represent 2,000 units and the totals have been compared.

2.3. Land Use

Communities were built for the Tbase typologies using ArcGIS. These communities included roads, sidewalks, water, waste water and stormwater distribution networks. The building structures as well as the infrastructure required to support them were included in the community models. Prototypes for each community type were designed based upon GIS data obtained from the City of Chicago and its western suburb of Naperville, IL. Road widths, sidewalks and alleyways were designed according to the relevant Chicago or Naperville code.

Infrastructure falling within the community boundary up to the entrance of each building was included in the GIS model. The infrastructure systems included potable water, stormwater and wastewater networks; electricity and telecommunications were not included.

2.4. Lifecycle Carbon

In order to estimate life cycle carbon emissions it was necessary to calculate the embodied carbon for each community. This included above grade infrastructure (roads, sidewalks etc.), utilities infrastructure (potable water, wastewater and stormwater) and the buildings.

For the embodied carbon calculations of the building

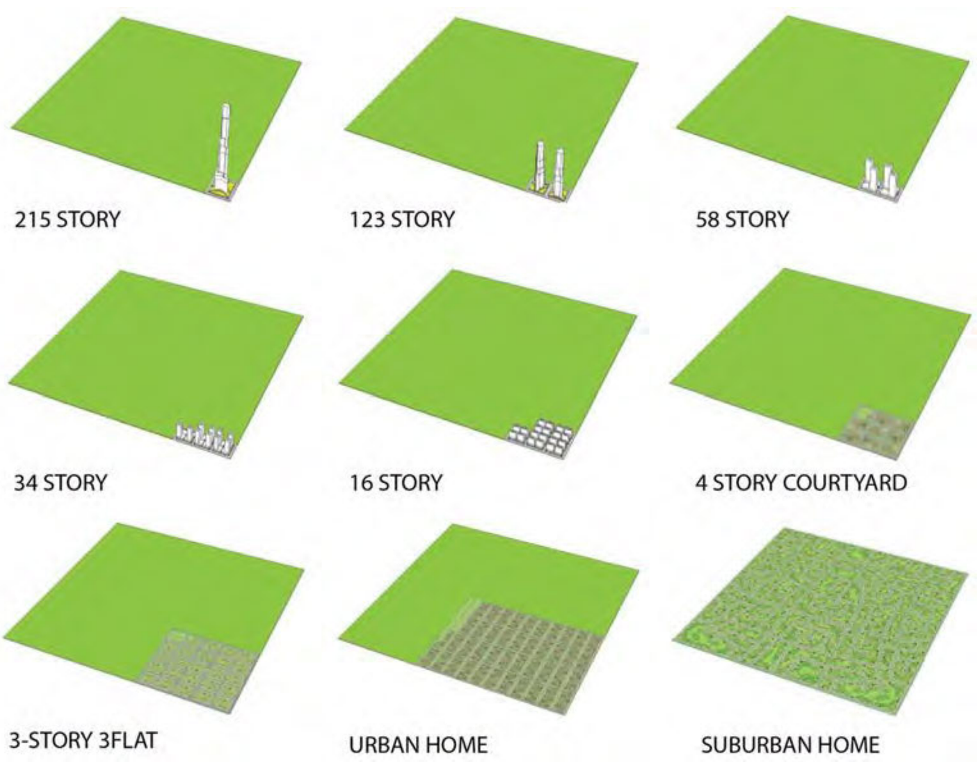


Figure 2. Community prototypes (Source: AS+GG).

Table 1. Community design parameters for the Tbase (market sized units) and T150 (150 m^2 units) typologies (Source: AS +GG)

T_{base} PROTOTYPE	215 STORY	123 STORY	58 STORY	34 STORY	16 STORY	COURTYARD	3-FLAT	URBAN SF	SUBURBAN SF
# Buildings	1	2	4	10	20	63	667	2,000	2,000
# Units / Building	2,000	1,000	500	200	100	32	3	1	1
# Storys (Above Grade)	215	123	58	34	16	4	3	2	2
Building Height (m)	773.0	442.0	208.5	122.5	59.5	14.0	10.5	6.5	8.6
Total Area (m$_2$)	498,240	258,473	85,511	30,505	17,120	3,833	351	257	287
Total Conditioned Floor Area* (m$_2$)	480,737	248,032	73,696	25,673	14,870	3,833	351	106	233
Net Residential Floor Area (m$_2$)	299,991	150,069	54,577	18,720	8,859	2,929	267	93	207
Average Unit Floor Area (m$_2$)	299,991	75,035	13,644	1,872	443	47	0	0	0
Mechanical Floor Area (m$_2$)	34,762	19,618	5,300	1,580	1,844	n/a	n/a	n/a	n/a
Parking Area (m$_2$)	44,400	23,600	8,424	4,010	2,106	-	-	41.00	47.80
% Efficiency	75%	75%	84%	89%	84%	86%	93%	100%	100%
Window / Wall Ratio	40.0	40.0	40.0	40.0	40.0	0.1	0.1	0.1	0.1
Parking Spaces Required	1	1	2	6	11	n/a	n/a	2	2
T_{150} PROTOTYPE	215 STORY	123 STORY	58 STORY	34 STORY	16 STORY	COURTYARD	3-FLAT	URBAN SF	SUBURBAN SF
# Buildings	1	2	4	10	20	100	667	2,000	2,000
# Units / Building	2,000	1,000	500	200	100	20	3	1	1
# Storys (Above Grade)	215	123	65	38	20	4	3	2	2
Building Height (m)	773.0	442.0	229.0	134.5	71.5	14.0	10.5	5.6	8.6
Total Area (m$_2$)	498,240	258,473	110,184	42,896	24,300	3,833	573	216	233
Total Conditioned Floor Area* (m$_2$)	480,737	248,032	98,392	37,834	21,000	3,833	573	171	177
Net Residential Floor Area (m$_2$)	299,991	150,069	75,039	30,077	14,980	2,995	450	150	150
Average Unit Floor Area (m$_2$)	150	150	150	150	150	150	150	150	150
Mechanical Floor Area (m$_2$)	34,762	19,618	6,293	2,108	2,232	n/a	n/a	n/a	n/a
Parking Area (m$_2$)	44,400	23,600	8,424	4,010	2,106	-	-	41.00	47.80
% Efficiency	75%	75%	84%	89%	86%	90%	92%	100%	100%
Window / Wall Ratio	40.0	40.0	40.0	40.0	40.0	14.6	9.6	7.0	10.9
Parking Spaces Required	1,100	550	275	110	55	n/a	n/a	2	2

*Based on energy model %, gross area

Other areas come from Excel area calculations

materials, the most significant (in terms of quantities) components of the constructions were analyzed: structures, building envelopes, insulation and interior partitions. Mechanical systems, wires and tubes, elevators, etc., were not included in the calculations. Quantities were taken from the building models described in the typologies section. The dimensions of the structural components were reviewed by structural engineers, who provided values for concrete strengths and reinforcement steel quantities.

The emissions factors for infrastructure and buildings were calculated using data from the Athena Institute, Bath ICE and the Concrete Pipeline Systems Association.

Transportation from place of manufacture to construction site was not accounted for in the study.

3. Results And Discussion

3.1. Energy Use

Energy consumption was considered in two ways-Total Energy Demand (TED, kWh/yr) and Energy Use Intensity (EUI, kWh/m2/yr). Figs. 3 and 4show the TED and EUI for the Tbase 2000 unit communities and Figs. 5 and 6 show the same data for the T150 communities. As the graph shows, the low-rise prototypes had six significant loads affecting their overall consumption: heating, cooling, interior lights, plug loads, fans and water heating. The high-rises had a total of nine loads (the other three being elevators, water pumps and heat rejection). Space heating and domestic water heating were the most energy intensive loads in almost all prototypes. Cooling became more significant in buildings with higher glazing ratios, where overheating occurs in summer.

In judging which of the Tbase buildings performs best, it is important to consider both EUI and TED as the unit sizes are different. In the T150 case, as the units sizes are the same in all typologies, the relationship between EUI and TED is constant.

The courtyard building was the most energy efficient of all the prototypes tested in both scenarios. A series of factors help explain these results: the high density of units, in a configuration where only two walls are exposed to the exterior, as well as a low glazing ratio. This helps contain the space heat in winter and reduce infiltration, as well as keep unwanted summer radiation out. The most significant load in this prototype was domestic water heating, because this value is not associated with environmental factors but with occupancy rates. Despite being a relatively dense prototype (with 32 or 20 units per building), the height still allowed it to operate with a simple system, not needing elevators or water pumping. Although not included in this prototype for the study, a single elevator would be required to allow disabled access up the building.

The high-rises (16 story, 34 story and 58 story) are much more interesting in terms of their performance; when looking at EUI (both scenarios) or TED in the T150 scenario the taller the building, the better it performs. Overall their energy consumption is greater than the low rise typologies, because these buildings have the added loads of water pumps and elevators, as well as higher loads for cooling, fans and, compared to some lower prototypes, higher lighting and plug loads as well.

The T150 suburban house performs reasonably well, on the other hand the market sized, Tbase suburban house would appear to perform very well in terms of EUI but because of its size (207 m^2 net residential area) the overall energy consumption is high.

In terms of energy use, the supertalls used the most energy out of all the prototypes. There are multiple factors associated with these results. First of all, these buildings depend on a series of spaces that are not residential

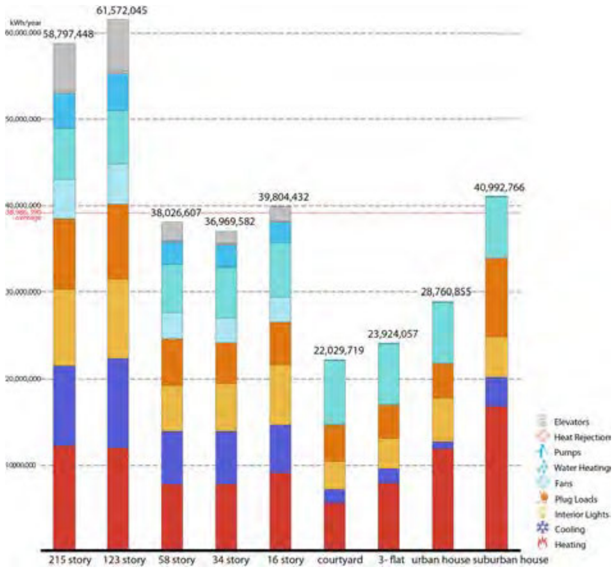


Figure 3. Total Community Energy demand for Tbase market sized units (Source: AS+GG).

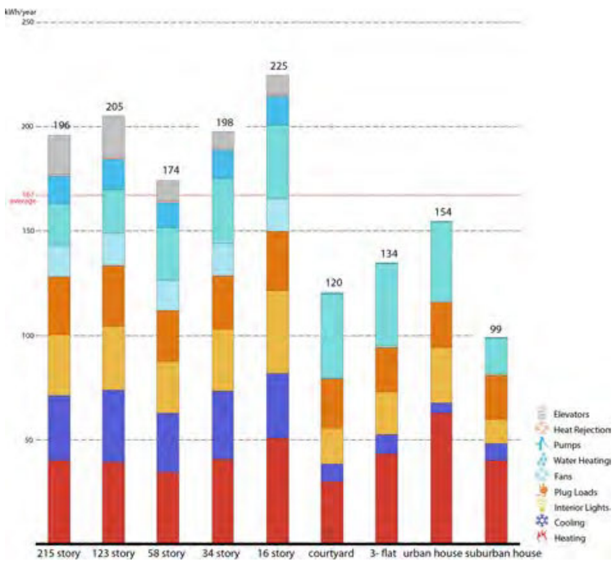


Figure 4. Energy Use Intensity for Tbase market sized units (Source: AS+GG).

units but account for around 30% of the total building area. Among these are the mechanical floors, the lobbies and amenities, and parking garages. These spaces are continuously illuminated and conditioned yet are not always occupied.

Architecturally, higher glazing ratios commonly found on these kinds of buildings perform poorly compared to the high mass envelopes of the lower prototypes. This typically translates into higher infiltration rates, heat losses in winter and unwanted heat gain in summer. Another aspect to take into account is elevators. An efficient ver-

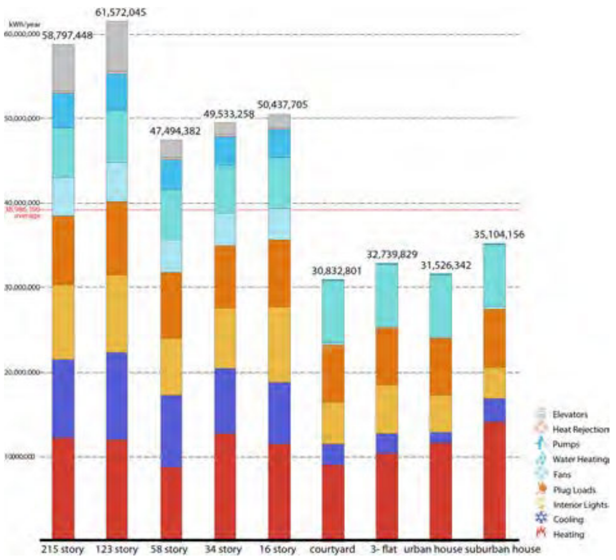


Figure 5. Total Community Energy demand for T150150 m² units (Source: AS+GG).

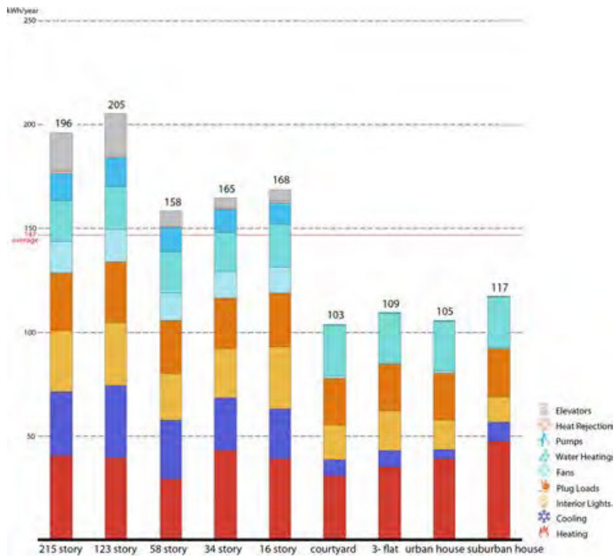


Figure 6. Energy Use Intensity for T150150m^2 units (Source: AS+GG).

tical transportation system is critical for the operation of supertall buildings, and it accounts for around 10% of the total energy consumption, compared to only four to six percent on other high-rises. Pumping energy also raises significantly, since water for mechanical systems and domestic uses needs to be pumped to higher elevations thus requiring more power.

An important aspect that was not accounted for in the study was the auxiliary energy required for the functioning of the smaller buildings. Auxiliary energy is considered to be any additional energy necessary for the operation of the prototypes that is not consumed within the building. Although systems like pumps and elevators are not part of these smaller buildings, other auxiliary systems replace these. For example, water distribution from the utility companies to these buildings at a certain pressure requires electricity. The potable water network in a suburban neighborhood of 2,000 single family homes is over 100 times longer than the one needed to supply one supertall building, resulting in increased auxiliary energy demand. Additionally it could be argued that the elevator energy demand, linking a residential unit almost directly to car-parking, replaces vehicle emissions associated with driving a car around a neighborhood (in the case of the two low-rise typologies).

3.2. Land Use

The study illustrates the extent to which the land use in lower rise communities is greater than that of high-rise communities; The Tbase suburban community occupies 110 times more land than a supertall tower housing the same number of units (see Table 2).

The land left undeveloped (see Fig. 2) in the high-rise and supertall developments could be used to mitigate the effects of the development. In an ideal scenario, the land could be left alone, which would preserve the natural habitat, protect wildlife and water sources and naturally sequester carbon. The land could also be used as farmland to support the demands of the growing population. For the purposes of this study, a scenario where 90% of the additional land is used to generate energy using Photovoltaic panels was considered. The NREL PVWatts calculator was used to estimate annual energy production assuming panel efficiencies of 18%, a Chicago weather profile and taking into account maintenance and shading packing factor. This analysis shows that the land difference between the Suburban Single family home typology is sufficient to meet the energy demands of all the other

Table 2. Land use of Tbase communities (Source: AS+GG)

T base PROTOTYPE	215 STORY	123 STORY	58 STORY	34 STORY	16 STORY	COURTYARD	3-FLAT	URBAN SF	SUBURBAN SF	SUBURBAN SF
Number of buildings	1	2	4	10	20	63	667	2,000	2,000	2,001
Total building footprint (m2)	3,177	7,534	16,848	20,050	42,120	60,376	78,039	335,650	394,765	394,766
Total area required (m2)	26,896	36,530	36,530	45,508	86,135	173,338	383,178	854,046	2,967,137	2,967,138
Land use as a % of suburban SF	0.91%	1.23%	1.23%	1.53%	2.90%	5.84%	12.91%	28.78%	100.00%	100.00%
Area compared to Suburban SF (m2)	(2,940,241)	(2,930,607)	(2,930,607)	(2,921,629)	(2,881,002)	(2,793,799)	(2,583,959)	(2,113,091)	0	1
PV Power generation , 90% landuse (kWh/yr)	249,500,094	248,483,237	248,483,237	247,722,001	244,277,279	236,883,423	219,091,300	179,166,873	0	1

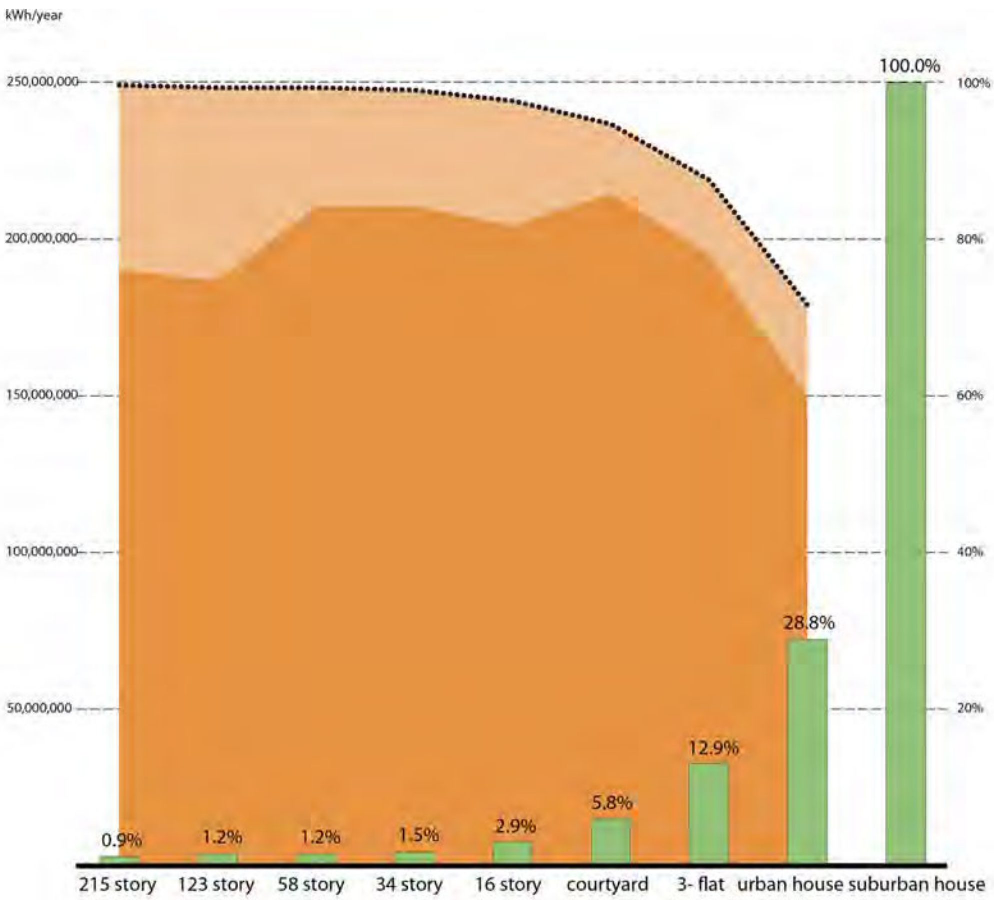
communities in the study (see Figs. 7 and 8). The best performing typology in both the Tbase and T150 scenarios is the 58 (65) story building, where the difference between energy generated on the unused land and energy consumption of the building is the highest, yielding a potential 238 GWh and 126 GWh of electricity per year in the Tbase and T150 scenarios respectively.

3.3. Life Cycle Carbon Emissions

The results of the Embodied Carbon EC analysis for Tbase are shown in Fig. 9. The EC of infrastructure directly correlates with land use. Spatially larger communities have greater lengths of roads and utilities to support the wider distribution of parcels, whereas taller buildings are confined to smaller plots with less external infrastructure. In these, some utilities move inside the buildings whereas other infrastructure (roads and sidewalks) is replaced by elevators and corridors.

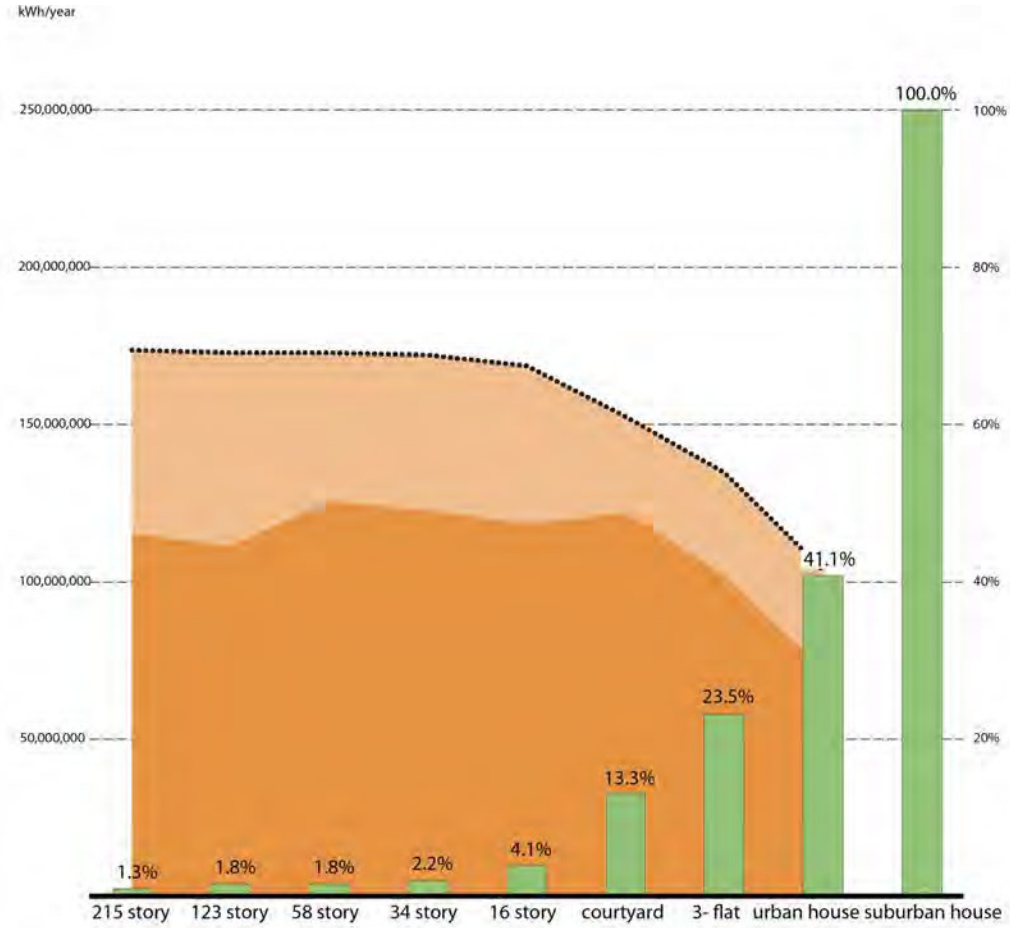
Regardless of community size (in terms of land area), the EC of buildings accounts for by far the greatest proportion of the communities' overall EC, with infrastructure accounting for only 0.15% in the supertall. However, it becomes more significant in the low rise typologies, rising from 3.7% in the courtyard community to 9.0% in the Suburban single family home community. The 213 story supertall community had a significantly higher embodied carbon than any other typology, primarily due to the amount of concrete and steel within the structure of the building. The typology that performed best in regards to embodied carbon was the 4 story courtyard building community.

The final element of the study was the estimation of lifecycle carbon emissions for the Tbase community. For this study, a 20 year period was used, as this represents a typical warranty period for photovoltaic systems. Although this is significantly less than the life expectancy of



26,896	36,530	36,530	45,508	86,135	173,338	383,178	854,046	2,967,137	Total Community Land Area (m²)
0.9%	1.2%	1.2%	1.5%	2.9%	5.8%	12.9%	28.8%	100.0%	Land Use, as % of Suburban Land Area
249,300,094	248,483,237	248,483,237	247,722,001	244,277,279	236,883,423	219,091,300	179,166,873	-	PV Generation on Available Land(kWh/yr)
58,797,448	61,572,045	38,026,607	36,969,582	39,804,432	22,029,719	23,924,057	28,760,855	40,992,766	Energy Consumption of Community (kWh/yr)
190,502,646	186,911,192	210,456,630	210,752,419	204,472,847	214,853,704	195,167,243	150,406,018	-	Remaining kWh of PV Power (kWh/yr)

Figure 7. Analysis of land use, energy demand and energy production potential for the Tbase communities (Source: AS GG).



26,896	36,530	36,530	45,508	86,135	277,109	487,880	854,046	2,076,996	Total Community Land Area (m^2)
1.3%	1.8%	1.8%	2.2%	4.1%	13.3%	23.5%	41.1%	100.0%	Land Use as % of Suburban Land Area
173,825,920	173,009,063	173,009,063	172,247,828	168,803,105	152,610,647	134,739,548	103,692,699	-	••• PV Generation on Available Land (kWh/yr)
58,797,448	61,572,045	47,494,382	49,533,258	50,437,705	30,832,801	32,739,829	31,526,342	35,104,156	Energy Consumption of Community (kWh/yr)
115,028,472	111,437,018	125,514,681	122,714,570	118,365,400	121,777,846	101,999,719	72,166,357	-	Remaining kWh of PV Power (kWh/yr)

Figure 8. Analysis of land use, energy demand and energy production potential for the T150 communities (Source: AS GG)

a high-rise building, 20 years is considered an acceptable time period for considering a major re-modelling and was therefore chosen as being appropriate for the purposes of this analysis.

The study included the embodied carbon, the operational carbon emissions and the amount of carbon offset by using the land saved (compared to suburban single family homes) for electricity generation from photovoltaics, as described earlier. This yielded a net relative carbon savings value (see Fig. 10) showing that the 58 and 34 story buildings provide the greatest overall net relative carbon saving, followed by the 16 story building and then the courtyard building.

3.4. General Discussion

The study reveals a number of interesting findings and direction for future study. In both the Tbase and T150 communities, the 4 story courtyard buildings had the lowest energy demand. However, in considering how energy demand across all typologies could be improved, this typology offers the least potential for improvement - the buildings already have a very low window to wall ratio (13.8%) and are well insulated in accordance with ASHRAE 90.1 energy standards. The taller buildings on the other hand offer the most potential for improvement - more efficient mechanical systems, vacancy and daylighting sensors, regenerative braking in the elevators, off peak thermal energy storage in basements, high performance glazing and reduction of the glazing ratios (from 40%) are just a few considerations that could be tested in the future. Moving to land use, when using the land area of the suburban single family home as a baseline, it is obvious that taller buildings will have a smaller footprint allowing the vacant land to be put to good use. For this study, using the

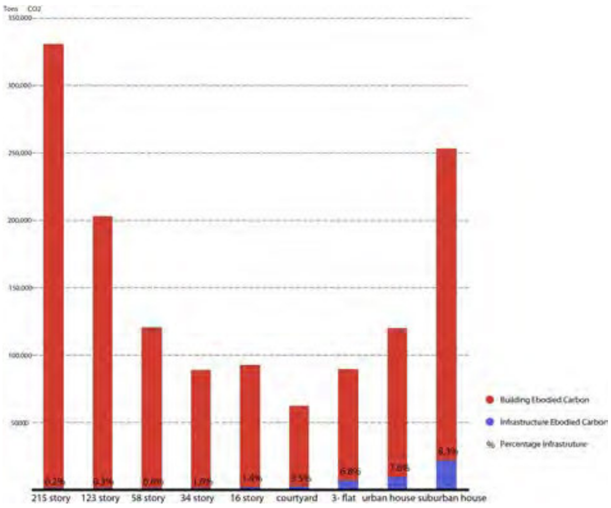


Figure 9. Embodied carbon of buildings and infrastructure for the Tbase communities (Source: AS+GG).

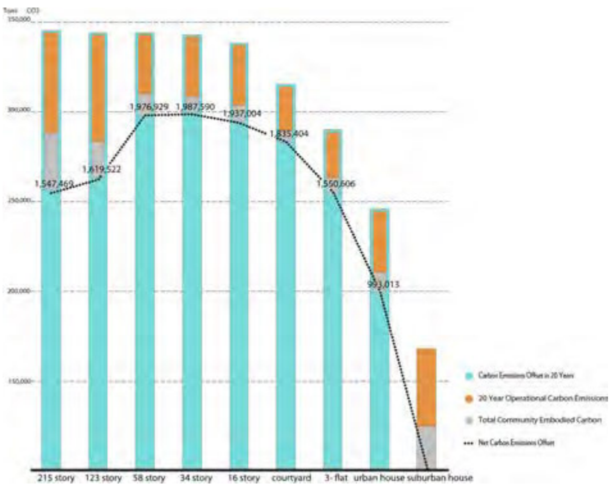


Figure 10. Lifecycle carbon analysis for the Tbase community (Source: AS+GG).

vacant land for power generation with photovoltaic was chosen - the study was conservative, assuming 90% of the land was used and that of that 90%, only 45% was covered with 18% efficient PV panels, to account for spacing and maintenance movement etc. Improvements in yield are clearly possible and could be considered as part of a future study. Secondly there are alternative uses for the land - loss of agricultural land, as mentioned in the introduction to the study is a global concern and is something that can be mitigated through building denser housing communities on marginal land. The net effect of using the vacant land for agricultural productivity or even carbon sequestration by natural systems is a subject for a future study.

Embodied carbon and lifecycle carbon emissions conclude this study, but to truly complete, it transportation should be further considered as improved connectivity with public transport and mass transit systems is typically thought of as one of the advantages of denser communities. For the present study, embodied carbon of infrastructure systems largely reflected land use, whereas as the embodied carbon of the buildings largely reflected the height of the individual buildings as far as the courtyard typologies before rising again through to the suburban single family homes. This is largely due to the relationship between structure and gross floor area being greater as buildings get taller. In the lower rise buildings, the choice of construction materials had a greater influence. Operational emissions were converted to CO2e using the grid emissions factor for Illinois. Clearly should the energy grid move over to cleaner forms of energy then operational emissions will become lower and embodied carbon will become more significant. Studying the impact of a reduced carbon grid and the effect of selecting low carbon construction materials is the subject of a future study.

Finally, taking into account operational emissions and potential carbon offsets through onsite energy generation, the communities that perform best overall are the high-rise buildings (58 and 34 story) with the taller buildings performing best.

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Article

Hybrid Life Cycle Assessment of Low, Mid and High-Rise Multi-Family Dwellings

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Abstract: We undertake Life Cycle Assessment (LCA) of the cumulative energy demand (CED) and global warming potential (GWP) for a portfolio of 10 multi-family residences in the U.S. We argue that prior LCA studies of buildings use an inconsistent boundary for processes to be included in the supply chain: The operational phase includes all energy use in a building, but supply chains for the production of appliances, equipment and consumables associated with activities done in the building are neglected. We correct this by starting the analysis with an explicit definition of a functional unit, providing climate controlled space, and including processes associated with this functional unit. Using a hybrid LCA approach, the CED for low, mid and high-rise multi-family residences is found to increase from 30, 34, to 39 GJ/m^2, respectively. This increase is due to the need for energy-intensive structural materials such as concrete and steel in taller buildings. With our approach, the share of materials and construction of total life cycle energy doubles to 26%, compared with a 13% share that would be obtained with inconsistent system boundaries used in prior studies. We thus argue that explicit definition of functional unit leads to an increase in the contribution of supply chains to building energy life cycles.

Keywords: life cycle assessment; functional unit; energy; greenhouse gases; economic input-output

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1. Introduction

The environmental impacts of urban structure have been a focus of research for many years. In 2007, the United Nations reported that cities were responsible for 75% of global energy consumption and 80% of all greenhouse gases (GHG). In 2013, however, the United Nations Environmental Program reported that buildings alone were responsible for about 40% of global energy and resource consumption, and approximately 33% of global GHG emissions [1,2]. Because buildings are a fundamental aspect of urban structure, it is important to understand their associated environmental impacts so that building design and use decisions can be made or incentivized in order to minimize these impacts.

Life cycle assessment (LCA) has become a common tool to examine the environmental impacts of industrial systems, including buildings. LCA is a "cradle to grave" approach that assesses the environmental impacts, such as the total energy consumed or GHG emissions produced, through its entire life cycle, or, as a result of raw material extraction, through the end-of-life of an industrial product or system. Life cycle assessment provides a picture of the environmental trade-offs often made in product or process selection and can help avoid shifting problems from one life cycle phase to another [3].

In the context of building LCA, the environmental impacts associated with the following life cycle phases are typically assessed: materials extraction and production (materials), building construction, building operation, and sometimes, renovation and deconstruction/disposal. One common finding from prior building LCA studies is the relative impacts from each of the life cycle phases: The operation phase consistently dominates the share of the total life cycle energy in conventional buildings, ranging from about 80%–95%, followed by materials production, ranging from about 5%–20% [4–9]. However, for highly efficient or passive buildings, the materials production phase ranges from 25%–77% of the total [6,10,11]. The significance of the materials production phase in total life cycle energy remains an area of focus [12,13].

LCA has often been used to compare the environmental impacts of buildings similar in function but varying in attributes such as construction materials or energy efficiency. Cole and Kernan [5] conduct an LCA comparing the total life cycle energy of three office buildings of similar size but varying in commonly used framing materials (wood, steel, concrete). They find that for all framing materials, the operation life cycle phase dominates the total life cycle energy and suggest that building designs should focus on strategies that reduce operation energy [5]. Adalberth [4] completes an LCA comparing the total life cycle energy of three single-family, detached wood-framed residences and find that the residence with a second floor consumed the least amount of operation life cycle energy due to lower transmission losses. Keoleian *et al.* [6] compare the total life cycle energy, GHG emissions and total life cycle costs of two U.S. single-family residences; one 'standard' and one energy efficient. The authors find that while the energy efficient home resulted in an approximately 60% reduction in life cycle energy and emissions, consistent with other findings, life cycle economic costs can be higher due to the increased costs of energy efficient materials [6,14,15]. Gong *et al*. [16] compare the total life cycle energy and GHG emissions of three multi-family residences of similar size but varying in commonly used framing materials (wood, steel, concrete). The authors find that the wood-framed residence resulted in the lowest environmental impacts while the concrete and steel-framed residences resulted in higher, yet comparable environmental impacts over the total life cycle [16]. Frijia *et al.* [17] assess the life cycle of a portfolio of single-family residences, the result being the construction of a family of parametric models describing the results as a function of size and construction type. Stephan *et al.* [11] examine the total life cycle energy through parametric analysis varying different aspects of the same representative Belgian passive home. The authors find that the embodied energy of passive homes can be as high as 77% of the total life cycle energy and suggest that more comprehensive system boundaries are required for building energy efficiency certifications to ensure net energy savings occur over the life span of the building [11].

We aim for three contributions with this manuscript. First, we clarify how explicit choice of functional unit is critical in defining what processes should be included in the boundary of LCA analysis. There is previous work highlighting the system boundary and the need for a more comprehensive framework [18,19]. We contribute to this debate by integrating functional unit into boundary choice. The fundamental issue is that many prior studies do not explicitly define functional unit, leading to inconsistent system boundaries [4–7,16,20]. In these and other studies, the operation phase is chosen to include all building energy use, suggesting that the functional unit encompasses all energy-using activities in the building. However, the ensuing LCA analysis excludes supply chains associated with many household activities such as production of appliances and consumer electronics. While exclusion of processes is a normal part of LCA, our point is that the lack of explicit choice of functional unit led to excluded processes not being identified as such. Taking the operation energy as total building energy use but only including supply chains for materials and construction overstates the contribution of operation in the life cycle. In contrast, this study starts with an explicit definition of functional unit: space conditioning (heating and cooling). This leads to corresponding supply chains accounting for building materials, construction and HVAC equipment.

Second, we examine the total life cycle energy, or cumulative energy demand (CED), and global warming potential (GWP) for a *portfolio* of 10 low, mid and high-rise multi-family residences. Examination of a portfolio enables exploration of how the changing structural requirements of taller buildings, which require more energy intensive construction materials (concrete and steel *vs*. wood), affect life cycle energy. Treloar *et al*. [21] studied the embodied energy in different types of existing office buildings varying in height, finding increasing embodied material energy with increased height. We pose a similar question regarding building height, though for residential buildings, and, with a broader scope of included processes (construction, operation, HVAC equipment manufacturing).

Third, we explore how household income changes the gap in energy use between single and multi-family homes. Previous LCA work finds that high (urban) density housing uses around half the energy of low (suburban) density counterpart [22]. While energy use per area is found to be similar between high and low-density housing, the much smaller size of a typical high-density residence resulted in lower total energy use per capita. In the context of urban planning and form, there is general agreement that single-family, or low-density housing, uses much more energy than multi-family, or high-density housing [23–26]. This assertion is primarily a function of two factors. The first factor is housing size: Single-family detached homes are generally larger than multi-family homes. The second factor is the surface area/volume (S/V) ratio; a single-family home has a higher S/V ratio, transferring heat more readily and consequently, consuming more energy [24]. However, in some cases, single-family homes consume similar energy as multi-family, partly due to relatively rapid improvements in energy efficiency of single-family homes over the last three decades [23]. Moreover, Heinonen and Junnila [27] find a higher relative net energy consumption in multi-family homes than single-family when the system boundary is expanded to include the consumption of goods and services.

While *on average* single-family homes use much more energy than multi-family ones, home size is highly heterogeneous. This heterogeneity correlates with demographics, e.g., wealthier families tend to live in larger homes. The gap in home size, and thus energy use, between single and multi-family homes could change as a function of income and other demographics. We thus analyze the impact of income and housing type on total energy consumed, or CED, by examining six different income levels while bounding the total CED to expected minimum and maximum values. While prior work has examined relationships between demographics, house size and energy use, e.g. [25], our analysis will clarify how income affects the gap in energy use for single-family and multi-family homes. This is important because urban planning efforts aimed to transition families from single to multi-family homes should account for how energy benefits vary depending on who is moving.

2. Methods

2.1. Functional Unit Choice and System Boundary

The definition of functional unit is fundamental in life cycle assessment. The functional unit is the unit of functionality associated with a product or service being studied [3]. To illustrate the idea, a functional unit to compare light bulb technologies could be defined as providing 10,000 h of 1800 lumens light. The reference flow is the associated product/service systems needed to deliver the functional unit, e.g., one 23-Watt compact fluorescent light bulb plus the electricity needed to power bulb. From the reference flow, one defines the supply chains to be included in the system boundary of the analysis (here production of bulbs and electricity).

The complication with buildings is their multi-functionality, with many different activities done inside them engaging a variety of other products. This multi-functionality has presumably been behind the functional unit not being explicitly defined in prior LCA building studies [4–7,16,20]. Not defining a functional unit has led to inconsistent system boundaries. To elaborate, Figure 1 outlines the logical flow of most prior energy LCA studies. The scope of the operational phase is chosen to include *all energy used in a building*. The implicit functional unit thus includes all activities undertaken in the building, which include preparing food, cleaning dishes and clothes, watching television and others. Supply chain processes included in the LCA typically cover structural materials and construction, sometimes including maintenance [18]. Many supply chain processes are excluded from the analysis such as manufacturing appliances, HVAC equipment, electronics, and consumable items. *These missing processes are not identified as excluded processes*. Core to LCA is the idea of clearly defining what supply chains relate to the functional unit, including as many processes as is feasible in the analysis, and clarifying what processes have been excluded. Not defining the functional unit in building LCAs has obscured the question of what processes have been excluded.

The solution to this problem is to start a building LCA with explicit definition of the functional unit to be considered. Figure 2 illustrates one example of this, beginning with the choice of functional unit as providing climate-controlled space. This leads to a reference flow of the building itself plus HVAC equipment. The boundary of the analysis is chosen to include operational energy for heating and cooling, materials and construction processes for the buildings, and manufacturing of HVAC equipment. There are still excluded processes (maintenance, demolition, landfill), but these are based on data availability. There are many other choices of functional unit that could include additional or different functions. Notably, Treloar and collaborators considered a functional unit of the lifestyle of residents, including building construction, operation, production of durable and consumable goods, services, and mobility [28]. In this larger lifestyle context, construction, maintenance and operation of the home accounted for 34% of total energy consumption of the occupants.

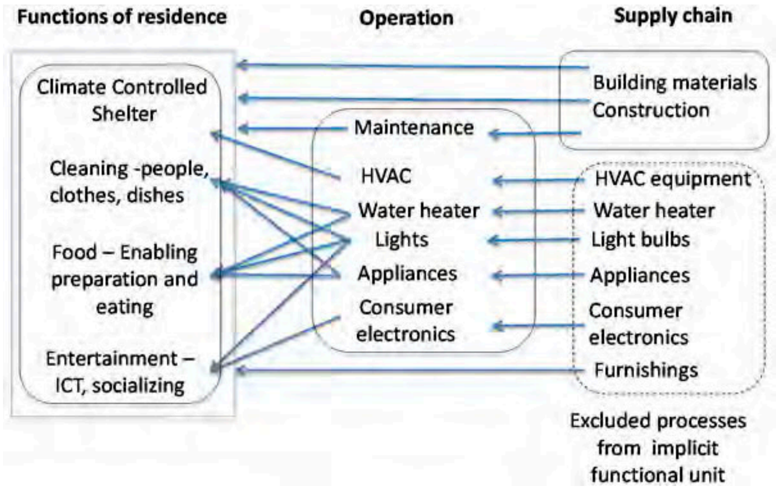


Figure 1. Typical inconsistent construction of system boundaries and implied functional unit for building energy Life cycle assessment (LCA). The operational energy is the total for the entire building, implying a functional unit that covers all activities done inside the building. Processes inside dashed box are excluded from analysis but not identified as excluded processes. Supply chains for consumables such as food could also be considered as excluded.

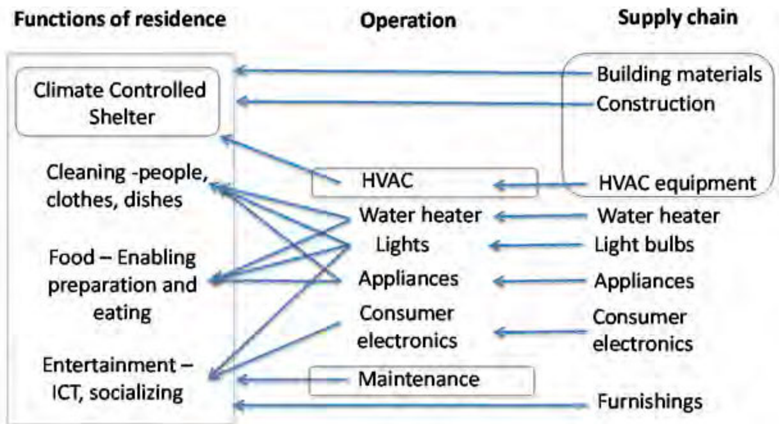


Figure 2. Example of consistent choice of functional unit (Climate Controlled Shelter) and included processes in building Life cycle assessment (LCA). While maintenance is in the list of processes that should be included, in this case study maintenance is excluded due to lack of available data.

This usual flow of a building LCA shown in Figure 1 leads to results that exaggerate the contribution of the operation phase the life cycle energy use and carbon emissions. The reason is that the operational phase includes all possible forms of energy use but many supply chains have been excluded. The procedure shown in Figure 2 will lead to an increase in the share of energy used in building manufacturing relative to operation.

2.2. Life Cycle Inventory

Three methods are generally used in practice to compile life cycle inventories: process-sum, economic input-output (EIO) and hybrid [29]. The most commonly used method is the bottom-up, process-sum approach that physically quantifies the energy and materials flows and the resulting environmental impacts for a product or system within the system boundary. The advantage of the process-sum approach is the potential to do a detailed analysis of a specific product or system. The challenges with using the process-sum approach include completeness, representativeness and accuracy of process and bill-of-materials data [29].

Alternatively, the top-down EIO approach is based on economic transactions between sectors of the economy [30]. In contrast to using physical quantities of energy and materials flows as in the process-sum approach, EIO uses financial transactions from sectoral input-output (IO) tables to estimate the supply chain materials use and associated environmental impacts [31,32]. The most detailed tables divide an economy into 400–500 sectors. As with the process-sum approach there are advantages and disadvantages to an EIO approach. Advantages of EIO include reduced time and resource requirements to complete an analysis compared to process-sum, and, as all supply chain activities are included as part of an EIO-LCA, truncation error is negligible. Since EIO-LCA includes activities such as services that a process-sum LCA generally does not, other factors kept equal, using EIO-LCA tends to increase net impacts accounted for due to the expanded boundary. However, EIO tables aggregate many processes or products into one sector, which can introduce significant aggregation error [29].

In order to capitalize on the strengths and minimize the weaknesses of each approach, a variety of hybrid LCA approaches have been proposed combining both methodologies [33,34]. The question how to achieve the most accurate combination of process-sum and EIOLCA methods is an open one [29].

We use a hybrid approach to compile life cycle inventories. We base our method choice on using best available data to address the questions posed. Our objective calls for bill-of-materials data for a variety for representative U.S. buildings of different heights and construction types. We found no source of physical requirements for a portfolio of buildings but did identify a well-known construction cost model that details bill-of-materials in economic terms [35]. The most detailed and standard source of residential building operational energy in the U.S. is the Residential Energy Consumption Energy Survey [36]. Given this data situation, we use EIO-LCA for the manufacturing of buildings and process-sum for operation.

Our hybrid approach follows in the family of additive approaches, in which some parts of the supply chain are analyzed using the process-sum method and others using EIO [17,34,37,38]. In particular, the method is based on the fundamental equation:

$$E_{Total} = E_{materials} + E_{construction} + E_{operation} \tag{1}$$

E_{Total}, the total energy of the building life cycle, is normalized by area. $E_{materials}$ is determined using additive EIO-LCA using an economic bill of materials. Let j be an index denoting items for material price, then

$$E_{materials} = (\Sigma P_j \cdot E^{SC}{}_j)/\mathit{total\ area\ of\ residence} \tag{2}$$

P_j is the price, $E^{SC}{}_j$ is the energy intensity of the relevant supply chain sector in MJ/$ [39]. $E_{construction}$ is the construction energy determined by an economic allocation method according to the value of business done in the multi-family construction sector, and, the price and energy intensity of the fuel consumed during construction. Let j be an index denoting type of fuel, then

$$E_{construction} = (BV \cdot \Sigma P_j \cdot E^F{}_j)/\mathit{total\ area\ of\ residence} \tag{3}$$

BV is the business value of a multi-family residence, P_j is the price and $E^F{}_j$ is the energy intensity of the relevant fuel per dollar. $E_{operation}$ is the operation energy determined by the process-sum method according to the total primary energy and intensity of each fuel consumed for space conditioning (heating and cooling) divided by the total area of the residences conditioned.

$$E_{operation} = \mathit{primary\ energy\ of\ fuels\ consumed/total\ area\ of\ residence} \tag{4}$$

Consumption of fossil fuels and electricity is converted to Cumulative Energy Demand (CED) (gigajoules) and Global Warming Potential (kg CO_2 equivalent) reported in [40], e.g., 3.36 GJ/kWh and 759 grams CO_2eq/kWh for electricity. These factors reflect a process-sum life cycle model of average fuel production in the continental U.S. [40].

2.3. Exploring Effects of Income on Life Cycle Energy of Multi- and Single-Family Homes

On average, multi-family homes are smaller and use less energy than single family homes. The average square footage of a multi-family home (apartments in 5 or more unit buildings) in the U.S. is 78.9 m^2 (849 ft^2) [41], which corresponds to a total life cycle energy of around 2370–3160 GJ. The average square footage of a single-family detached home is 230.7 m^2 (2483 ft^2) [41], which when using results from [17] corresponds to a total life cycle energy of around 4620–5540 GJ. Similar to results found for [11,22,42], a single family home uses about double the energy per capita of a multi-family home, primarily due to the size difference.

As discussed in the introduction, home size, and thus energy use, varies considerably by family. Urban planning efforts to encourage people to move from single to multi-family homes in general do not target an average homeowner, but rather specific groups that may be different from the average. It is therefore important to find patterns in homeowner groups that correlate with variability in home size. Income is obviously one important factor, thus we analyze how the size of single and multi-family homes changes with income and then map this to life cycle energy use.

Average square footage by income level and housing type data (single-family detached and apartments in five or more unit buildings) comes from the Energy Information Administration [36]. Ranges of CED per area (GJ/m^2) for multi-family housing are found by bounding the results of the current multi-family LCA (minimum and maximum values from all building types studied). Similarly, ranges for CED (GJ/m^2) for single-family detached housing are established by bounding the life cycle materials and construction energy values from [17].

3. Analysis

3.1. Object of Analysis

Two impact categories are analyzed: cumulative energy demand (CED) (GJ/m^2) and global warming potential (GWP) (CO_2eq/m^2), as defined in [43]. As previously discussed, the inventory flows for each life cycle within the system boundary are quantified as follows: the life cycle inventory of materials are quantified through an EIO-LCA approach, the construction life cycle flows are quantified through an economic allocation approach, and, the operation life cycle flows are quantified through a process-sum approach (Figure S1 in the supplementary documentation illustrates the system boundary diagram). The functional unit is the delivery of a controlled climate space to a multi-family residence for 50 years, consequently including energy and GWP contributions solely from heating and cooling during the operation life cycle phase. The reference flow includes 10 different multi-family residences and their associated heating ventilation and cooling (HVAC) systems. Table 1 details the parameters for the 10 multi-family residences which are used to generate representative bills of materials (BOMs) for the multi-family residences [35].

Table 1. Parameters used to develop ten multi-family dwelling bills of materials for the Economic Input-Output portion of the hybrid life cycle assessment (LCA).

Number of Stories	Rise	Square Feet	Square Meters	Exterior Wall	Frame	Perimeter (meters)
3	Low	30,500	2837	Wood siding	Wood Frame	56
3	Low	30,500	2837	Stucco on Concrete Block	Wood Joists	56
4	Mid	65,000	6045	Precast Concrete Panels	Steel Frame	74
4	Mid	65,000	6045	Precast Concrete Panels	Reinforced Concrete Frame	74
7	Mid	60,000	5580	Precast Concrete Panels	Steel Frame	47
7	Mid	60,000	5580	Precast Concrete Panels	Reinforced Concrete Frame	47
11	High	80,750	7510	Ribbed Precast Concrete	Steel Frame	37
11	High	80,750	7510	Ribbed Precast Concrete	Reinforced Concrete Frame	37
21	High	216,500	20,135	Ribbed Precast Concrete	Steel Frame	51
21	High	216,500	20,135	Ribbed Precast Concrete	Reinforced Concrete Frame	51

3.2. Materials Contribution: Economic Input-Output Life Cycle Assessment (*LCA*)

The EIO approach is economic-based, using the environmental impact intensities of the associated U.S. economic sectors used in the production of a product or process. For this study, energy and GWP intensities for U.S. economic sectors are obtained from the Carnegie Mellon University Green Design Institute (CMU GDI) input-output model [39]. This publicly available model includes the 2002 input-output tables that contain 428 U.S. industry sectors based on the North American Industry Classification System (NAICS) [39,44]. In conjunction with environmental impact intensities, the EIO approach often uses producer prices (PP) to determine environmental impacts. Producer prices can be thought of as the price "at the gate" of a producer, thus differing from consumer price by prices of transport, wholesale and retail distribution. Typically, prices for each line item on a bill of materials are provided in terms of an end user's purchasing price, including prices associated with overhead and profit (O&P). In order to appropriately reflect producer price, material line item prices are adjusted using producer/purchaser ratios (PPR) that are part of the input-output model [45]. In addition, producer price indices (PPI) are used to adjust material line item prices to reflect the desired time frame of the study [46]. Let j be an index denoting items with material price from a BOM of a multi-family dwelling, then

$$PP_j = (P_j)\cdot(PPR_j)\ (PPI_{2002j}/PPI_{2010j}) \tag{5}$$

PP_j is the producer price, P_j is the extended material price in USD (O&P removed), PPR_j is the producer/purchaser ratio for the relevant economic sector, and, PPI_{2002j}/PPI_{2010j} is the producer price index ratio associated with the economic sector in 2002 and 2010. Tables S1 and S2 in the supplementary documentation contain a sample BOM used in this study, as well as the PPI, PPR CED and GWP intensity values for the economic sectors used in this study. Table 2 demonstrates how a line item from a BOM connects to its associated economic sector, PPR, PPI and CED intensity.

Table 2. Example of how a bill of material line item connects to an economic sector and the total contribution of a line item to life cycle CED during the materials life cycle phase.

Line #	Line Item Description [a]	Extended Material Price [a] ($)	EIO Sector [d]	PPR [b] × PPI [c]	CED Intensity [d] (MJ/$)	CED (MJ)
8	Structural concrete, ready mix, normal weight, 3000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments	510	237320 Ready mix concrete manufacturing	0.49	23.5	5882

EIO: Economic input-output; PPR: Producer/purchaser ratio; PPI: Producer price index; CED: Cumulative energy demand; MJ: Megajoules; $: Dollar; All values detailed in Tables S1 and S2 in the supplementary documentation. [a] Source [35]; [b] Source: [45]; [c] Source: [46]; [d] Source: [39].

Contributions to CED/GWP from each material line item, denoted by the index j, is calculated using the following equations:

$$CED_j = (PP_j)(E^{SC}{}_j) \tag{6}$$

$$GWP_j = (PP_j)(GWP^{SC}{}_j) \tag{7}$$

CED_j and GWP_j are the materials life cycle energy and GWP, respectively, PC_j is the producer price calculated previously in Equation (5), and, $E^{SC}{}_j$ and $GWP^{SC}{}_j$ are the energy and GWP intensities of the relevant supply chain sector, respectively. Table 2 contains the contribution to CED for a line item of a bill of material used in this study (5882 Megajoules).

Finally, the contributions to CED and GWP as a result of the materials life cycle phase is calculated by summing the CED/GWP for individual line items and then normalizing by area:

$$E_{materials} = \sum_{n=1}^{n} CED_j \textit{/total area of multi-family residence} \quad (8)$$

$$GWP_{materials} = \sum_{n=1}^{n} GWP_j \textit{/total area of multi-family residence} \quad (9)$$

$E_{materials}$ *and* $GWP_{materials}$ are the life cycle energy and GWP for the materials life cycle, respectively, and CED_j and GWP_j are the materials life cycle energy and GWP calculated previously using Equations (6) and (7), respectively. Data and calculations for each building is detailed in the Microsoft Excel file posted online as part of the supplementary documentation for this article.

3.3. Construction: Economic Allocation Approach

The economic allocation approach is used to quantify the input and output flows contributed by the construction life cycle phase, or, those flows that occur as a result of the erection of the multi-family residence such as fuels consumed during transportation, electricity production and equipment use. The contributions to CED and GWP during the construction life cycle phase are based on the value of business done and energy purchases made in 2002 by the associated NAICS sector, 236116, New Multifamily Housing Construction [47]. This approach is taken in order to focus on one type of construction process, multi-family residences, to mitigate aggregation error. According to the 2002 Economic Census, the New Multifamily Housing Construction sector reported a business value of \$17 billion and spent \$1.2 million in energy purchases [47]. As a result, 20 PJ of energy were consumed in 2002, which is equivalent to 1.2×10^{-3} GJ of primary energy consumed and 7.8×10^{-5} tCO_2eq emissions produced per dollar of business done. Table S3 in the supplementary documentation details the energy and GWP values used in the calculations.

The business value (BV) of a multi-family residence is calculated using the total extended material, labor and equipment prices from the multi-family BOM (see Table S1 in the supplementary documentation for a sample), plus O&P adjusted to reflect 2002 values. According to industry standards, the O&P for material, labor and equipment are 10%, 68%, and 10%, respectively [35]. Further, the PPI was obtained using historical construction price indexes [35]. The following equation is therefore used to calculate the BV for a multi-family residence:

$$BV = (1.1 \cdot MC_{total} + 1.68 \cdot LC_{total} + 1.1 \cdot EC_{total})\ (0.7) \quad (10)$$

BV is the business value of a multi-family residence, MC_{total} is the total extended material price, LC_{total} is the total extended labor price, EC_{total} is the total extended equipment price from a multi-family BOM, and 0.7 is the historical price index for construction between 2002 and 2010 [35]. Therefore, the contributions to CED and GWP as a result of the construction life cycle phase are calculated using the BV per multi-family residence (10) and the energy and GWP intensities per dollar spent calculated previously, and then normalized by area, or:

$$E_{construction} = (1.2 \times 10^{-3}) \textit{BV/total area of multi-family residence} \quad (11)$$

$$GWP_{construction} = (7.8 \times 10^{-5}) \textit{BV/total area of multi-family residence} \quad (12)$$

$E_{construction}$ *and* $GWP_{construction}$ are the energy and GWP for the construction life cycle phase, respectively.

3.4. Operation: Process Approach

This study quantifies the primary input and output flows, or inventory, contributed by the heating and cooling processes during the operation life cycle phase. The life cycle inventory (LCI) for the operation life cycle phase is obtained from microdata from the 2009 Residential Energy Consumption Survey (RECS) conducted by the U.S. Energy Information Administration [36]. The microdata is grouped into multi-family dwelling rise (low, mid and high, Table 1) based on the number of floors in an apartment building with five or more units [48]. An apartment/multi-family residential building with one to three floors is considered low-rise, with four to seven floors is considered mid-rise, and, with more than seven floors is considered high-rise. The primary consumption of electricity, natural gas and fuel oil for the purpose of space conditioning (heating and cooling) as well as for all activities, is examined. These fuels represent approximately 99% of the share of energy consumed in these particular apartment buildings [48]. Tables S4 and S5 in the supplementary documentation contain details of the LCI for this phase. The contribution to CED as a result of the operation life cycle phase (50 years) for low-, mid- and high-rise multi-family residences is 25, 26.5 and 29.5 GJ/m^2, respectively. Similarly, the contribution to GWP as a result of the operation life cycle phase (50 years) for low-, mid- and high-rise multi-family residences is 1.45, 1.60, and 1.70 tCO2eq/m^2, respectively.

Finally, the contributions to CED and GWP from each life cycle phase are added together. For example, the total life cycle energy, or CED, for a low-rise multi-family dwelling is determined by following Equation (1):

$$E_{Total(low\text{-}rise)} = E_{materials(low\text{-}rise)}\,(8) + E_{construction(low\text{-}rise)}\,(11) + E_{operation}\,(25\mathrm{GJ/m^2}) \tag{13}$$

Similarly, the total life cycle GWP for a low-rise multi-family dwelling is determined using the following equation:

$$\begin{aligned} GWP_{Total(low\text{-}rise)} = {} & GWP_{materials(low\text{-}rise)}\,(9) + GWP_{construction(low\text{-}rise)}\,(12) \\ & + GWP_{operation}\,(1.25\mathrm{tCO_2eq/m^2}) \end{aligned} \tag{14}$$

4. Results

4.1. Multi-Family Life Cycle Impact Assessment

Results shown in Figures 3 and 4 indicate that CED/GWP increase from low to mid to high-rise. This finding may be attributed to two factors. First, there are increased structural requirements that occur when going from low-to mid- to high-rise dwellings. For example, in a low-rise multi-family dwelling, wood framing can be used. Wood has a comparatively lower overall CED/GWP, when considering total mass and energy intensity, than steel or concrete which are alternative framing materials required for higher-rise multi-family dwellings. The second reason that the study suggests a direct correlation between increases in CED/GWP and building rise is due to the increasing operation energy. While this study uses survey data to complete the analysis for operation energy, the findings are corroborated by empirical work completed in Vancouver, BC on mid and high-rise residential buildings [49]. Values for CED/GWP for each life cycle phase are found in Table S6 in the supplementary documentation.

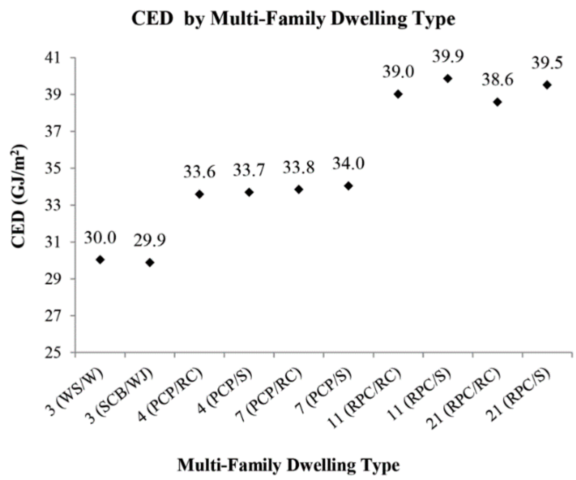


Figure 3. Cumulative Energy Demand (CED) for multi-family dwellings of different construction and number of stories. CED: Cumulative energy demand; GJ/m^2: Gigajoules per square meter; WS/W: Wood siding/wood frame; SCB/WJ: Stucco on concrete block/wood joists; PCP/RC: Precast concrete panels/reinforced concrete: PCP/S: Precast concrete panels/steel; RPC/RC: Ribbed precast concrete/reinforced concrete; RPC/S: Ribbed precast concrete/steel.

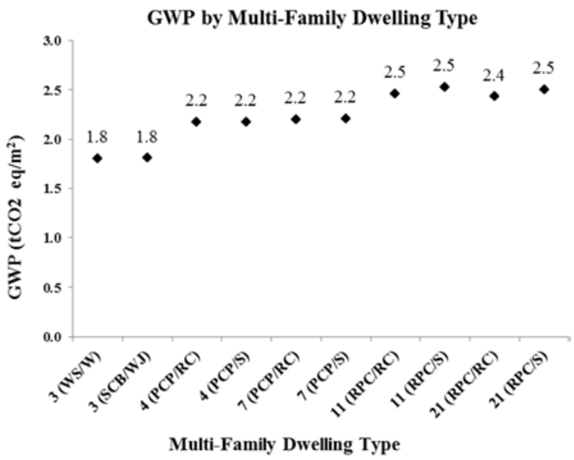


Figure 4. Global Warming Potential (GWP) for multi-family dwellings of different construction and number of stories. GWP: Global warming potential; WS/W: Wood siding/wood frame; SCB/WJ: Stucco on concrete block/wood joists; PCP/RC: Precast concrete panels/reinforced concrete: PCP/S: Precast concrete panels/steel; RPC/RC: Ribbed precast concrete/reinforced concrete; RPC/S: Ribbed precast concrete/steel.

The results shown in Figure 5 show that for the 11-story multi-family dwelling, total life cycle energy, or CED, is approximately halved when defining a functional unit only including HVAC activities compared to the same dwelling when all operational energy is included. The share of materials and construction correspondingly increases from 13%–26% when restricting operational energy to HVAC. This change in perspective does not overturn the conventional wisdom that operation phase dominates (for a conventional, not energy efficient, building), but now at ~1/4 of total energy, materials and construction are much more important contributors to life cycle energy.

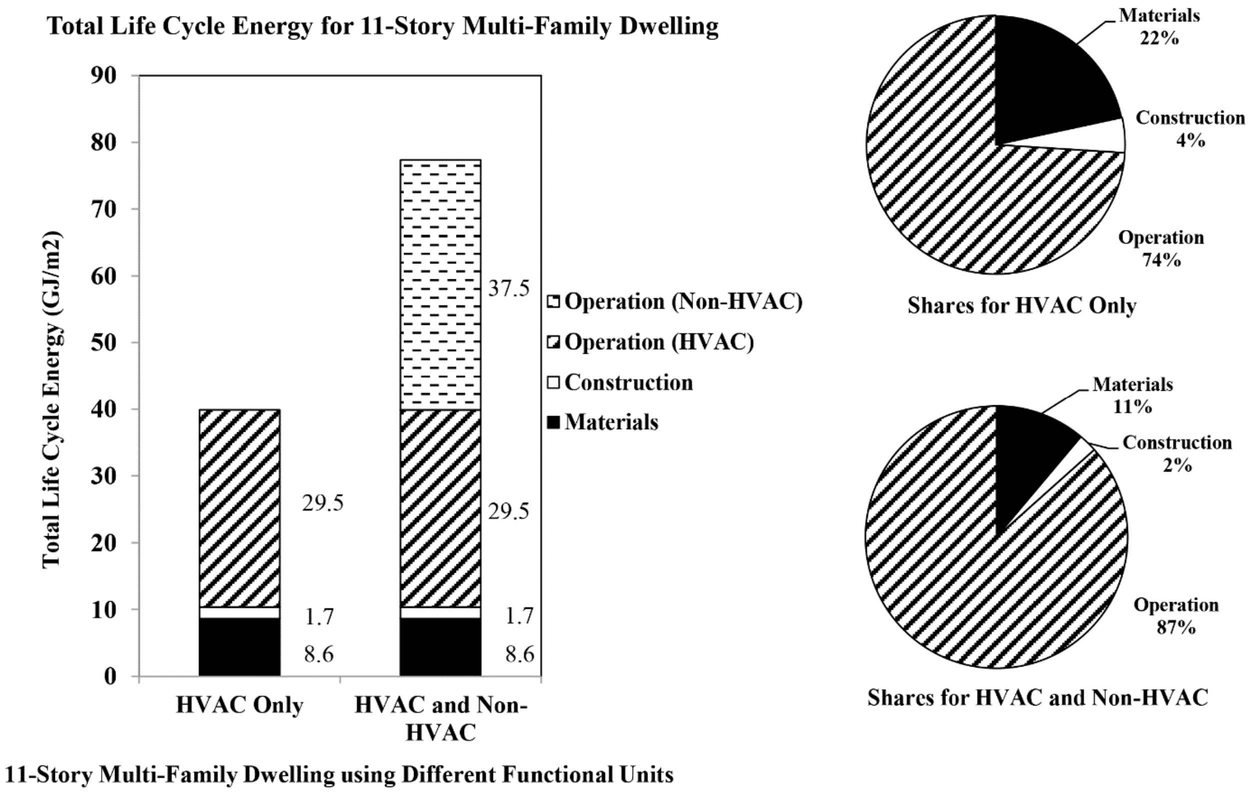
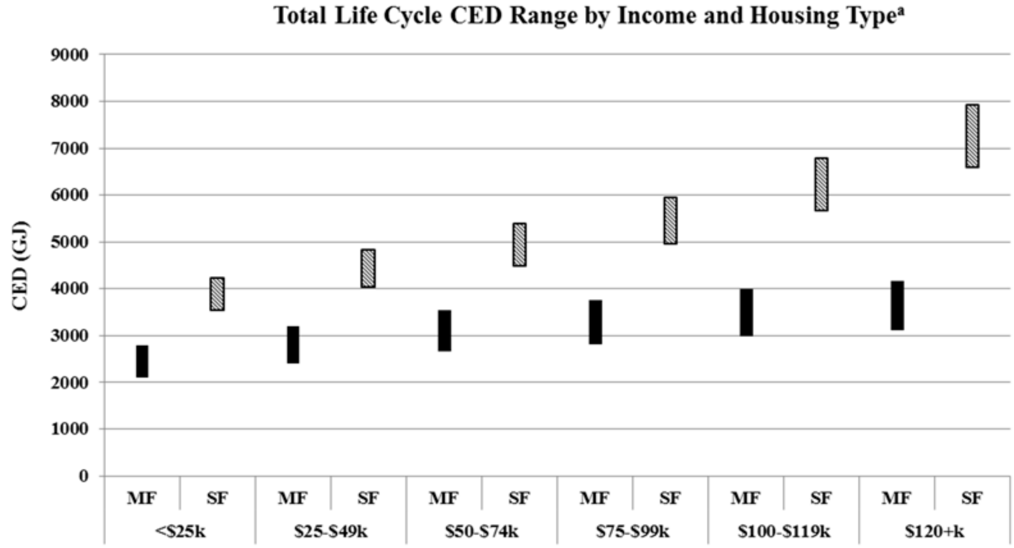


Figure 5. Life cycle shares of CED for an 11-story multi-family dwelling for a functional unit including heating and cooling (HVAC) only and all energy (HVAC and Non-HVAC), the latter reflecting inconsistent boundaries used in prior studies (see Section 2.1). CED: Cumulative energy demand; GJ/m^2: Gigajoules per square meter; HVAC: Heating, ventilation and air conditioning.

4.2. Comparing Multi-Family and Single-Family Detached Residences for Different Incomes

The results shown in Figure 6 indicate that total life cycle energy increases with income for both housing types. In all cases the total life cycle energy of single-family detached housing is greater than multi-family housing. Moreover, total life cycle energy of single-family detached homes increases with income more quickly than for multi-family homes (greater than four times). In the lowest income range, the gap in CED between single-family detached to multi-family housing is in the range of 26%–100%. In contrast, in the highest income range, the difference in CED is in the range of 58%–153%. The results suggest socioeconomic influences on total life cycle energy. It is important to point out that this analysis only includes building materials, construction and energy to operate HVAC. According to the Energy Information Administration (EIA), the share of energy consumed for heating and cooling has decreased from 53% in 1993 to 48% in 2009, while the share of energy consumed for appliances, electronics and lighting has increased from 24%–35% during the same time frame [50]. A broader view including the impacts of the consumption of goods and services has been shown to be greater in higher density (multi-family) residences [23,27].



	MF	SF	MF	SF	MF	SF	MF	SF	MF	SF	MF	SF
CED Low (GJ)	2100	3526	2404	4022	2659	4479	2814	4944	2993	5654	3123	6589
CED High (GJ)	2799	4231	3205	4827	3545	5375	3752	5933	3991	6785	4164	7906
Ave m²	70	176	80	201	88	224	94	247	100	282	104	329

Figure 6. Total life cycle CED by Income and Housing Type. CED: Cumulative energy demand; MF: Multi-Family Residence; SF: Single-Family Residence; k: Thousand US$; GJ: Gigajoules; Ave: Average; m^2: Square meters. [a] Sources: Materials and construction life cycle data on single-family detached homes is from [17]. Operation life cycle data for single-family detached homes was determined using [48] for primary heating and cooling consumption data, and, [51] for total number of single-family detached homes and total square footage. An average U.S. site to source factor of 3.365 for electricity is used [40]. Data on multi-family homes is from the current study. Average square footage by income level and housing type (apartment in building with 5 or more units and single-family detached homes) comes from [36].

5. Discussion

5.1. Main Results

Regarding the definition of functional unit, we illustrated for one choice (climate controlled shelter) that explicit definition significantly alters the balance of energy use between supply chains and operation. We argue that all subsequent building LCA studies should start by defining the functional unit. This choice could be different from ours, e.g. include more or different activities within a residence or other type of building. Since prior studies have excluded many supply chain processes, in general we expect that defining the functional unit will in general lead to a lower share of the operation phase compared with previous practice.

In our exploration of life cycle energy as a function of building height, qualitatively we see a similar trend as [21] of increasing energy use per area with increasing height. Including operational and construction energy, there is a 30% increase in GJ/m^2 from three to 11–21 storey buildings. This increase is due to use of more energy-intensive construction materials such as steel and concrete as compared to wood construction with higher building height. We expected to see operational energy per area decreasing with increasing building height (due to more shared floors/ceilings), but the U.S. Residential Energy Consumption Survey [36] (see Section 3.4) showed the opposite trend. Further work is needed to clarify this point.

The socioeconomic analysis is relevant for urban planners. It is widely assumed that compact urban form, a big component of which is multi-family housing, will result in large energy savings [22]. The degree of savings is, however, highly dependent on what types of consumers are moving from single to multi-family homes. Depending on who is moving from single to multi-family homes, the energy savings can be much smaller or much larger than "average". The assessment of energy savings from a compact urban development needs to account for the demographics and prior lifestyles of residents moving to the development. While there are certainly prior regression results that show how energy use changes with income and multi *vs*. single family [25], our results show a transparent trend that accounts for the life cycle.

5.2. Uncertainty

As with any modeling exercise, there are many limitations to the analysis. To first recap the factors not included in our model, maintenance of the building, replacement of equipment, variability in building lifespan, and the variability of GHG emission factors over the 50-year time scale were excluded. The first three factors we neglected due to lack of available data, the last due to lack of methodological standard. Still, these are all important issues to be addressed in the future, e.g. previous work has found that the impacts from maintenance, or refurbishment of building materials, can be significant [19]. Accounting for these factors will probably not affect the qualitative trend found here.

Turning next to accuracy of the factors that were included in the analysis, one question is the error associated with using EIO-LCA. Using EIO-LCA almost always introduces more aggregation error than a process-sum analysis. However, the relative accuracy of EIO-LCA and process-sum remains an open question [29]. One issue complicating a comparison is that LCA studies, like this one, often aim to answer general questions about a class of products (*i.e*. single *versus* multi-family buildings). There is an enormous degree of variability between individual products, asserting a characteristic of the class requires knowledge of the average. In principle, variability can be handled with process-sum analysis. In practice, however, process-sum analysis often proceeds with a small sample of a product or process, sometimes only one. The representativeness of such a limited sample for the general class is unclear. More work is needed to clarify aggregation error in EIO-LCA and representativeness and truncation error in process-sum analysis to enable a proper comparison of the two approaches. In addition, EIO and process-sum LCA have differing degrees of temporal and geographical uncertainty, also important to consider [28].

Another area of uncertainty involves the BOMs for multi-family residences. The detailed BOM's are price estimates primarily used to assist contractors in developing quotes for the construction of buildings [35]. While providing a detailed list of line items, the BOMs are estimates only, introducing parameter uncertainty due to potentially inaccurate or missing data. Treloar *et al.* 2001 [21] used data from existing buildings rather than estimates of representative buildings and found higher relative embodied energy. There is also parameter uncertainty in the operation life cycle phase. Low-, mid- and high-rise operation data for U.S. multi-family dwellings is obtained from the Residential Energy Consumption Survey [50]. This data is weighted based on the number of households estimated to have similar characteristics including consumption characteristics [52]. Despite potential parameter uncertainty in the operation data, the trend found that operation energy increases with building rise is corroborated in previous empirical work [49]. When comparing the overall findings to the results of previous studies, no inconsistencies of concern arise (See Table S7 in the supplementary documentation for more on comparison with prior results).

To conclude, we draw the reader's attention back to the functional unit issue. There is decades of history of LCA studies of buildings. The typical flow of analysis is (1) To *not* define the functional unit, (2) Take the operation phase as all energy use in the building, and (3) Exclude supply chains associated with many activities done in the building. This practice exaggerates the contribution of building operation to life cycle impacts. There is a need to reexamine LCA practice for buildings for different explicit definitions of a functional unit.

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Author Contributions

Kimberly Bawden collected the data, performed the analysis and wrote most of the paper. Eric William's contributions were guiding the direction of the research, writing some sections, and editing.

Conflict of Interest

The authors declare no conflict of interest

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Decoupling density from tallness in analysing the life cycle greenhouse gas emissions of cities

Francesco Pomponi[1,2✉], Ruth Saint[1], Jay H. Arehart[1,3], Niaz Gharavi[1] and Bernardino D'Amico[1]

The UN estimate 2.5 billion new urban residents by 2050, thus further increasing global greenhouse gases (GHG) emissions and energy demand, and the environmental impacts caused by the built environment. Achieving optimal use of space and maximal efficiency in buildings is therefore fundamental for sustainable urbanisation. There is a growing belief that building taller and denser is better. However, urban environmental design often neglects life cycle GHG emissions. Here we offer a method that decouples density and tallness in urban environments and allows each to be analysed individually. We test this method on case studies of real neighbourhoods and show that taller urban environments significantly increase life cycle GHG emissions (+154%) and low-density urban environments significantly increase land use (+142%). However, increasing urban density without increasing urban height reduces life cycle GHG emissions while maximising the population capacity. These results contend the claim that building taller is the most efficient way to meet growing demand for urban space and instead show that denser urban environments do not significantly increase life cycle GHG emissions and require less land.

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INTRODUCTION

Population and urbanisation are increasing with an estimated additional 2.5 billion people living in urban areas by 2050[1]. The built environment is the greatest cause of carbon emissions, global energy demand, resource consumption and waste generation[2]. In the European Union (EU), it accounts for 50% of all extracted materials, 42% of the final energy consumption, 35% of greenhouse gases (GHG) emissions and 32% of waste flows[3]. Therefore, achieving optimal use of space and maximal efficiency in buildings is fundamental for the transition to sustainable built environments and to progress towards national and international climate targets.

The design of urban environments has not rigorously considered life cycle GHG emissions (LCGE hereon), focusing instead on reducing the operational energy demand and the carbon emissions associated with the energy used to operate buildings. Operational energy use occurs while the building is in service, and includes heating and cooling, lighting, and other plug loads. The use of operational energy contributes to the LCGE of a system as the energy grid is not carbon free, thus conversion factors can be applied to convert between units of energy used and carbon dioxide equivalent (CO_{2e}), the metric of LCGE. LCGE includes these operational emissions as well as the embodied emissions of the entire system. Embodied energy and CO_{2e} emissions are the hidden, "behind-the-scenes" energy and emissions that are used or generated during the extraction and production of raw materials, the manufacture of the building components, the construction and deconstruction of the building, and the transportation between each phase[4]. As operational efficiency grows, so does the share of embodied impacts on the whole-life balance, thus reinforcing the need for sustainability analyses of buildings and cities to be underpinned by a life-cycle-based approach[5,6]. In other words, operational energy and carbon savings should not be made at the expense of the embodied impacts, and a holistic approach focused on reducing LCGE should be the primary aim.

Apart from a few studies focusing on urban morphology and energy demand[7,8] in the built environment, there has been a growing belief that building taller and denser is better, under the idea that tall buildings make optimal use of space[9], reduce operational energy use and energy for transportation[10,11], and enable more people to be accommodated per square metre of land[12]. However, this is only partly true. As buildings grow taller they need to be built further apart; for structural reasons, urban policies and regulations, and to preserve reasonable standards of daylight, privacy and natural ventilation[13]. Furthermore, for a fixed amount of internal volume (e.g. expressed in terms of floor area times the inter-storey height) an increase in the building's tallness corresponds to an increase of the building slenderness and hence to a reduction of its compactness which is detrimental to space optimality[14]. Urban density is commonly defined as the ratio of built land area (i.e. building footprints) to total land area yet this metric does not capture building height.

Height has been captured in urban density metrics by summing the total floor space of an urban environment and dividing by the total land area[15]. To date, however, no method exists to (i) analyse density and tallness of urban environments independently of each other or (ii) evaluate their influence on the LCGE of urban environments. These are the two main objectives of this paper. To decouple the two (i.e. density and height) we propose an additional metric for describing urban environments through a 'tallness' factor, or the average height of an urban area. This informs a method that includes a model to generate synthetic, yet realistic, parametric urban environments based on a number of input variables, as detailed in the Methods section. To embed such realism, we collected primary data on real urban environments since building regulations vary greatly across any one country, due to the devolved powers of local authorities in matters of urban planning. Therefore, picking any single value for building

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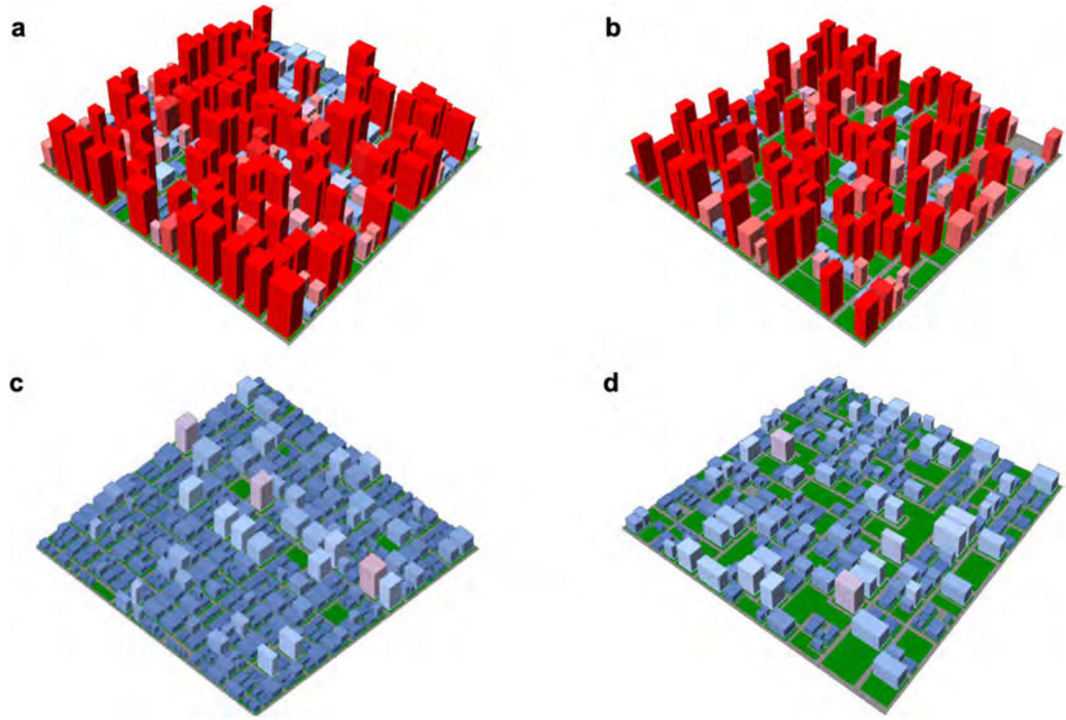


Fig. 1 Illustration of the different of urban typologies classified in the present analysis. a HDHR, **b** LDHR, **c** HDLR, **d** LDLR. The height of each building is mapped to the colour with blue as low heights and red as high heights.

footprint, sizes, number of storeys, distance with adjacent buildings, etc. could bias our results. As an alternative, we surveyed 25 addresses in the UK (in the cities of London, Edinburgh, Glasgow, Manchester, Leeds, Sheffield and Birmingham) to measure these key building characteristics and neighbourhood constraints. The choice of the addresses we surveyed was due to proximity to the authors to ensure a good coverage of the key inputs to our analysis and the possibility of site visits where needed. In the attempt to avoid a sole UK focus of our study, we verified these primary collected data against spot checks in the European cities of Berlin, Oslo, Stockholm and Vienna, obtaining good agreement.

For each of the 25 addresses we surveyed, we extended our analysis to 1 km^2, with each building at the centre, and collected the following data: number of blocks, number of green spaces, average block perimeter, average block area, average green space perimeter, average green space area, average street width, average main road width, average distance to surrounding buildings, and width and depth of the building plot (including gardens, driveways, etc.). These inputs ensure the synthetic urban environments stem from real-world observations. For each urban environment we assess, at the building level, both embodied and operational emissions to inform a whole-life set of results. While our model and method are applicable irrespective of the geographical context of analysis, the results of their application—while aimed at a broad European context—remain rooted in UK primary data. The results for such context are shown in the next section.

RESULTS

Density and tallness of urban spaces

Urban environments are diverse, arguably unique, and the product of many factors such as the landscape, culture, economy and history. Yet, a common theme throughout urban environments is the types of buildings that comprise them. These can be categorised as non-domestic low-rise (NDLR); non-domestic high-rise (NDHR); domestic low-rise (DLR); domestic high-rise (DHR); and terraced or semi-detached houses (House)[16,17]. Full details are given in the Supplementary Information (specifically Supplementary Methods 1, Supplementary Table 1 and Supplementary Methods 3). The layout and combination of these different building types contribute to both the density and height of an urban space[13,18–20].

In this study, we offer a LCGE analysis of urban environments by decoupling and analysing both tallness and density. Through our method, we parametrically simulate 5000 urban environments under two scenarios and perform a cradle-to-grave process-based life cycle assessment on each to evaluate the LCGE. Scenario 1 considers fixed populations of 20, 30, 40 and 50 thousand people with varying land area, while Scenario 2 considers a fixed land area of 1 km^2 with varying populations potentially supported. We compare the LCGE of each urban environment to evaluate if taller and denser environments yield greater efficiency in terms of accommodated population, land use, energy demand and GHG emissions. This multi-criteria approach provides a more holistic picture of the LCGE of urban environments and can inform better policies and practice related to urban design and planning.

While a large variety of urban typologies could be defined with respect to density and height, we define four typologies for discussion herein: high density, high-rise (HDHR); low density, high-rise (LDHR); high density, low-rise (HDLR); and low density, low-rise (LDLR). Examples of these urban environments are visualised in Fig. 1. An area of midtown Manhattan in New York City, USA, is an example of a HDHR urban typology with a density factor of approximately 54.5 and a tallness factor of 54.2. Central Paris is an example of a HDLR urban typology with a maximum density factor of 62.6 and tallness factor of 7.5. LDLR urban typologies are commonplace in suburban metropolitan areas, or urban "sprawl," while LDHR environments have been envisioned by many urban planners, notably by Le Corbusier's design of the "Radiant City"[21]. Details around the determination of the cut-offs for each urban typology (Supplementary Discussion and Supplementary Methods 1) as well as the procedural flowchart of the algorithm behind our model are given in the Supplementary Information (Supplementary Methods 2).

For each of the five types of building considered herein, the LCGE results are presented in Table 1, separated by life cycle stage as defined by BS EN 15978:2011[4]. As expected, the structural system of each building contributes significantly to the cradle-to-gate emissions. With a 60-year lifespan assumed for all buildings[22], the operational impacts represent between 77–83% of the LCGE. Non-domestic buildings typically have higher LCGE than domestic buildings, while high-rise buildings have greater LCGE than low-rise buildings which is consistent with findings from other studies[5,23,24]. These LCGE results for different building types feed into the 5000 parametrically simulated urban environments which are explored under the two previously defined scenarios.

Table 1. Embodied carbon coefficients (ECC) and operationa carbon coefficients (OCC) used to determine a LCGE coefficient for each bui ding type, norma ised per square metre of floor area.

	ECC (A1-A3 Structure)[25] $kgCO_2e\ m^{-2}$ FA	ECC (A1-A3 Façade)[26] $kgCO_2e\ m^{-2}$ EA	ECC (A1-A3 Roof)[27] $kgCO_2e\ m^{-2}$ BF	ECC (Stage A4)[6] $kgCO_2\ t^{-1}\ km^{-1}$	ECC (Stage A5&C)[6] $kgCO_2e\ m^{-2}$ FA	OCC (over 60 years)[a] $kgCO_2e\ m^{-2}$ FA	LCGE $kgCO_2e\ m^{-2}$ FA
Non-domestic ow-rise	180	72	21	0.19	221	2460	**2953**
Non-domestic high-rise	250	168	21	0.19	221	2460	**3120**
Domestic ow-rise	180	76	33	0.19	221	1898	**2426**
Domestic high-rise	250	61	33	0.19	221	1898	**2462**
Terraced/house	90	84	36	0.19	221	1491	**1925**

[a]Derived from operationa energy estimates for non-domestic bui dings[28] and domestic bui dings[29].
Units are given be ow each e ement considered; structure, façade and roof ECCs a refer to Stage A1-A3 (i.e. from raw materia extraction to manufacturing genera y referred to as crad e-to-gate). A4 refers to transportation to site and A5 to construction activities in ine with the EN 15978 termino ogy on a bui ding's ife cyc e stages. *FA* floor area, *EA* enve ope area, *BF* bui ding footprint.

Scenario 1: fixed population

Figure 2a illustrates the LCGE of all simulated urban environments for the four population scenarios: 20, 30, 40 and 50 thousand people, while Table 2 shows key results for LCGE and land area (averages and standard deviations) for each population cluster. Across all four populations, the LCGE increases as tallness increases, independent of the amount of land required to house the population. In contrast, the density of buildings has little impact on LCGE; for each population, low- and high-density typologies result in similar LCGE results. If the simulated environments are separated into their height–density typologies, we find that between the LDLR and HDLR typologies, there is a decrease in the average LCGE as population increases: 10% decrease for a 20k population, 16% for 30k, 19% for 40k and 15% for 50k. A key difference between LDLR and HDLR typologies is the built land area required to accommodate the same number of people. HDLR typologies require 49–56% less land than LDLR, resulting in lower LCGE impacts and less demand for land. Percentages in the discussion of the results always refer to comparison across the averages reported in Tables 2 and 3.

High-rise buildings have much higher LCGE than low-rise buildings, as shown by the large bubbles in Fig. 2. Thus, building taller has a significant impact on the LCGE of an urban environment when the number of people is kept constant. For a 20k population, moving from a HDLR (small purple bubbles) to a HDHR (large purple bubbles) typology results in a 140% increase in LCGE; for 30k, 40k and 50k populations, the difference is 154, 143 and 132%, respectively. Compared with the difference between LDLR and HDLR typologies presented above, this shows the much greater impact of building taller over building denser.

From Table 2 it is possible to see that, for all the fixed populations, HDLR buildings minimise LCGE. HDHR is the worst-case scenario for all populations, ranging from a 27 to 77% increase in LCGE when moving from a 20k to a 30k and 50k population, respectively. However, the impact on LCGE with increasing populations is higher for the other urban typologies, despite absolute LCGE being much higher. For a LDLR scenario, doubling the population, i.e. from 20k to 40k, results in an 81% increase in LCGE; moving from 20k to 50k gives a 94% increase. In terms of increasing impacts with greater populations, LDHR shows the highest differences; 112% LCGE increase moving from 20k to 40k and 145% moving from 20k to 50k. This suggests that the land required, and thus the land use change emissions factor, to accommodate higher populations plays a role in LCGE. This is reflected in the larger land areas required when building low-dense typologies for higher populations; in a LDHR scenario, moving from 20k to 30k results in a 53% increase in land area and from 30k to 40k and 50k populations, the difference is 115 and 152%, respectively. However, the small absolute LCGE increase does not reflect the large increase in land required suggesting the relatively insignificant impact land use change has on LCGE.

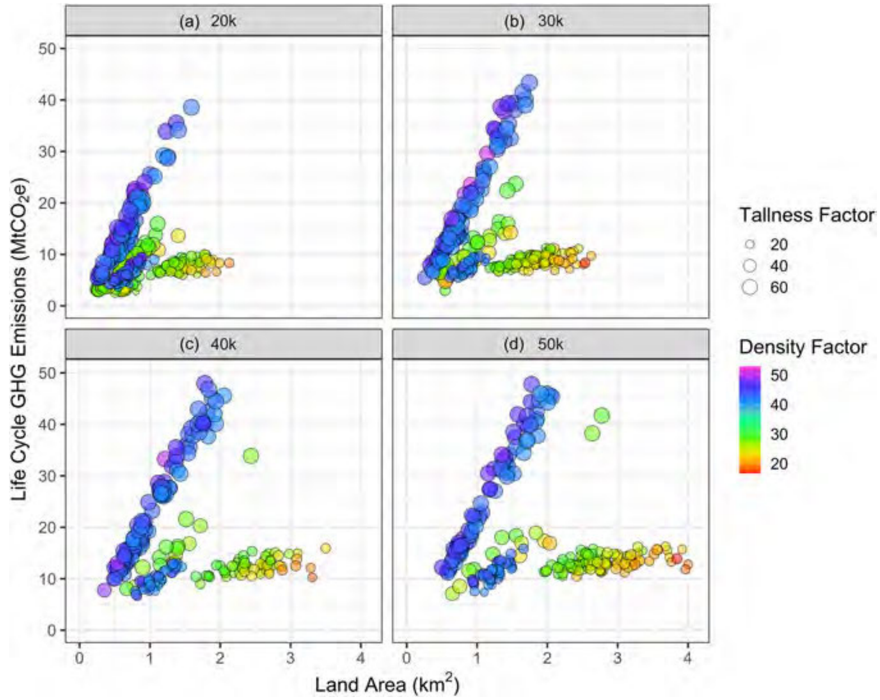


Fig. 2 LCGE versus built land area for fixed populations. Results presented for 20 (**a**), 30 (**b**), 40 (**c**), and 50 (**d**) thousand people.

Table 2. Summary of the LCGE and built land area with fixed populations for the four scenarios.

		LDLR		LDHR		HDLR		HDHR	
		Average	Std. dev.	Average	Std. dev.	Average	Std. dev.	Average	Std. dev.
20k	LCGE ($MtCO_2e$)	6.82	2.08	7.44	3.46	6.12	1.52	14.68	7.07
	Land area (km^2)	1.32	0.41	0.62	0.29	0.67	0.14	0.65	0.26
30k	LCGE ($MtCO_2e$)	8.69	1.21	11.20	4.75	7.32	1.18	18.60	9.79
	Land area (km^2)	1.82	0.34	0.95	0.35	0.84	0.12	0.81	0.36
40k	LCGE ($MtCO_2e$)	12.37	1.49	15.8	6.20	9.98	1.83	24.25	10.88
	Land area (km^2)	2.48	0.41	1.33	0.42	1.11	0.19	1.07	0.44
50k	LCGE ($MtCO_2e$)	13.2	1.38	18.2	9.94	11.2	1.83	26.01	11.4
	Land area (km^2)	2.81	0.49	1.56	0.65	1.24	0.17	1.16	0.46

The distribution of building types across the four population models is shown in Fig. 3. For the higher populations (40k and 50k), proportionally more domestic buildings are selected in order to accommodate the need for more residences. This need is particularly illustrated through the 50k population model in which domestic low-rise buildings dominate any other building type across all simulations.

When LCGE is normalised per building type, non-domestic buildings have the highest share of the impact at 75% (62% for non-domestic high-rise and 13% for non-domestic low-rise), so their inclusion in the urban scenario inherently increases LCGE. Domestic buildings account for the remaining 25% with the following split: 17% for domestic high-rise and 4% for both domestic low-rise and terraced/house. This split in LCGE impact aligns with the results presented in Table 1. As expected, non-domestic buildings are responsible for the largest portion of LCGE due to having higher operational emission intensities. This value will become less significant as a driver for higher non-domestic impact in future years due to the decarbonisation of the grid and reduced reliance on fossil fuels[25]. Therefore, the next hotspot to address from a LCGE perspective is the structural system of buildings, which is largest in high-rise buildings, both domestic and non-domestic. Beyond that, the largest difference is seen in the façade; non-domestic high-rise buildings have at least twice the impact of the other four building types, due to the heavy material intensity of steel and glass[26,27].

In terms of land area, the difference between LDHR and HDHR urban typologies is not as stark as the low-rise scenarios. The LDHR scenario requires between 17–34% more land for a 30k population and 50k population, respectively. Essentially, more people require more space, but high-rise buildings require a similar land area compared to low-rise buildings with varying density. This is due to the space required when building taller; buildings must be further apart for structural reasons, urban policies and occupant comfort. Therefore, building taller to accommodate a growing population not only does not save space but also significantly increases LCGE. A note here might be on whether the additional empty space between high-rise buildings is transformed into urban greenery that can sequester carbon. Evidence in support of this can be found in the work of Zirkle and colleagues[28], who modelled carbon sequestration in home lawns in the US finding a technical sequestration potential ranging from 25.4 to 204.3 g C m^{-2} $year^{-1}$. Their work covers different US zones with their own climates, ranging from cases

Table 3. Summary of the LCGE and population accommodated with a fixed land area for the four urban typologies.

	LDLR		LDHR		HDLR		HDHR	
	Average	Std. dev.	Average	Std. dev.	Average	Std. dev.	Average	Std. dev.
LCGE ($MtCO_2e$)	7.11	0.60	15.10	3.02	8.79	1.16	24.98	2.69
Population (thousands)	21.04	5.19	42.69	12.70	46.66	12.65	57.80	18.98
LCGE per capita	0.34	0.12	0.35	0.24	0.19	0.09	0.43	0.14

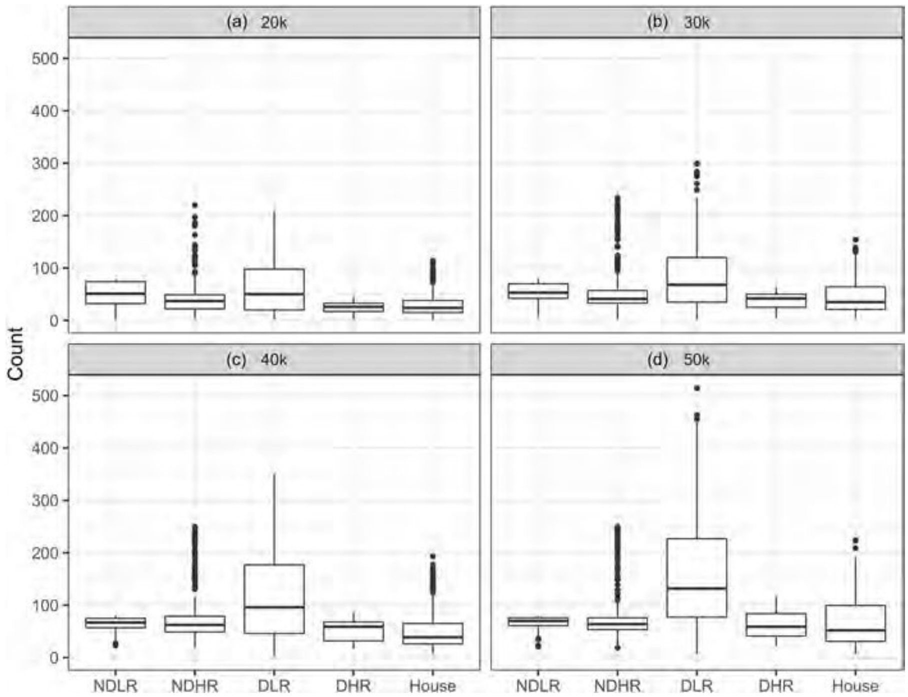


Fig. 3 Count of building types for each simulated urban environment across the four population models. Results presented for 20 (**a**), 30 (**b**), 40 (**c**) and 50 (**d**) thousand people. Quantitative comparison between the typologies in our synthetic environments and those observed in real urban environments showing good agreement is offered in the SI (Supplementary Fig. 3).

(arid southwest) where the lawn management (energy, irrigation, fertilisers, etc.) can offset the net carbon sequestration to others (northeast) where best practices for lawn management show a significant and promising net carbon sequestration potential. We are therefore unable to immediately translate such values into inputs to our model to capture carbon sequestration of urban greenery, but this undoubtedly is an important point for future work.

Figure 4 presents the LCGE as a function of the tallness and density factor for each fixed population. This visual representation shows that LCGE increases with increasing height and that high-rise buildings are more commonly paired with high density typologies. Furthermore, this representation illustrates that the LCGE of different densities is less stratified than for building height, reinforcing the finding that building height has a significant impact on LCGE, while density does not.

Scenario 2: fixed land area

Figure 5 illustrates the LCGE for different combinations of density and height for a fixed land area of 1 km^2. This plot is more variable and does not show the same trends that were identified in Fig. 2. There is a pattern whereby LDLR (small red bubbles) exhibit the lowest LCGE and HDHR (large purple bubbles) have the highest. Therefore, in this scenario, LDLR is the best-case in terms of minimising LCGE and HDHR is the worst. However, LDHR can accommodate 103% more people than a LDLR scenario and HDLR and HDHR scenarios can accommodate 122–175% more, respectively. On average, more than twice as many people can be accommodated in a HDLR scenario for a similar LCGE, with 21k people at 7.11 $MtCO_2e$ for LDLR and 47k people at 8.79 $MtCO_2e$ for HDLR. Thus, HDLR would offer a better solution; invest 24% more carbon to accommodate 122% more people. With high-rise scenarios, LCGE significantly increases compared to LDLR; 112 and 251% more LCGE in LDHR and HDHR scenarios, respectively. Therefore, the carbon investment does not seem justified. Changing the density from low to high has little impact on the LCGE in low-rise scenarios, as shown in Table 3. However, moving to high-rise structures results in a significant impact on LCGE with a 184% increase moving from HDLR to HDHR.

DISCUSSION

With an aim to evaluate the widespread belief that building dense and tall is the only way to accommodate a growing urban population, we developed and employed a method to separate density from tallness in urban environments and establish the extent to which each influences the LCGE of cities. Indeed, the difference between varying urban scenarios and across varying populations had yet to be quantified from a LCGE perspective. We found that while tallness does significantly increase the LCGE, density does not, and we here suggest that there is an alternative

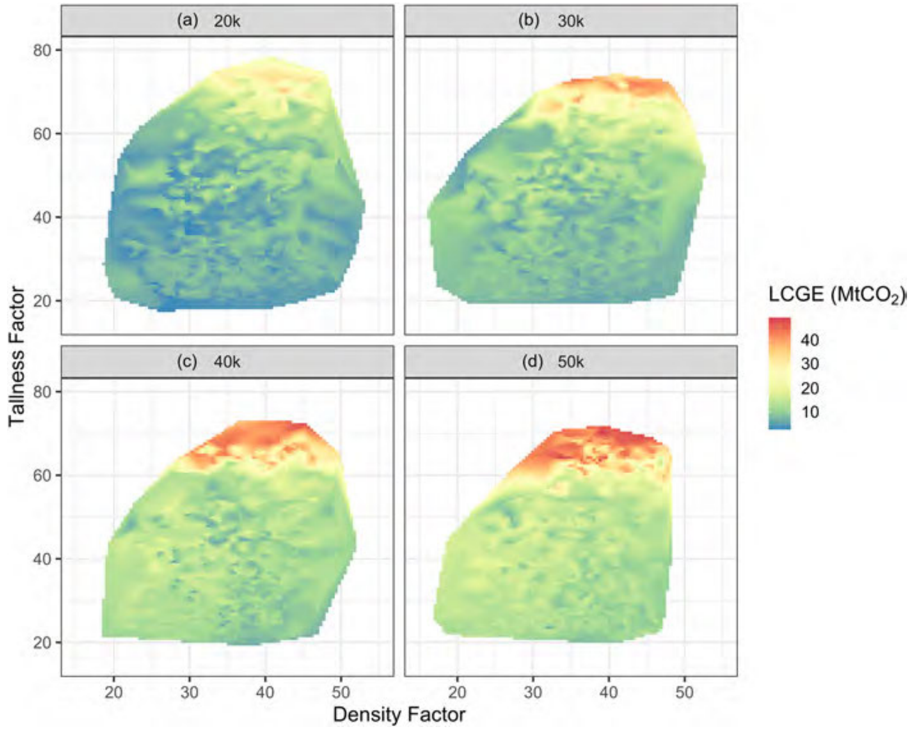


Fig. 4 Colour maps for the fixed population conditions under investigation. Results presented for 20 (**a**), 30 (**b**), 40 (**c**), and 50 (**d**) thousand people. A spline interpolation is used to interpolate between each simulated urban environment.

low-rise pathway for urban development that can meet the growing demand for urban floor area. While not explored in detail, it is worth considering that low-rise urban environments also allow to choose from more construction materials than the handful of elite materials that govern and dominate our high-rise built environments (i.e. steel, reinforced concrete, aluminium and glass).

Specifically, in terms of LCGE impacts, HDLR urban typologies are the best-case scenario for a fixed population. This can even be argued to be the case for a fixed land area, despite a higher absolute LCGE output than the LDLR typology, due to the much greater number of people that can be accommodated. For the case of fixed populations, it may be surprising that LDLR typologies do not have the lowest impact. However, due to the larger land areas required to accommodate the same population, the land use change factor pushed the impact past that of HDLR though there is only a relatively small difference between them (10–19%). Given the growing pressure and competing demands on land as a resource it is however only reasonable to assume it is used as efficiently as possible, and this is what HDLR urban typologies do. The worst-case scenario for a fixed land area is the HDHR typology, as population does not constrain the number of buildings or type that can fit within the 1 km^2 boundary. For the fixed population conditions, the worst-case scenario is also HDHR (followed by LDHR) suggesting that there seems to be no supporting evidence behind the necessity for high-rise urban environments.

While simulation based, our synesthetic urban environments (i) stem from primary data collected in real-world neighbourhoods (Supplementary Methods 2 and 3 and Supplementary Note) and (ii) match well with the features revealed by analysis of today's cities (Supplementary Method 1 and Supplementary Fig. 3). As such they can effectively support both better urban policies and more environmentally sustainable urban design and planning. For instance, when new mixed-use neighbourhoods are being developed or redeveloped, our method and model can offer important insights to inform policies in order to meet the desired targets (e.g., population to be housed and/or non-domestic floor area to be achieved) while reducing LCGE. Similarly, in parts of the world where new cities are being built from scratch (e.g. China) or where this could happen in the near future (e.g. Africa) our research could support urban planning and design. Significantly, the EU/UK geographical context of our work only affects the underlying data and not the model and method which could feed off machine-readable data representative of any country in the world.

Future potential applications of the model and method could investigate 'optimal' values for urban density and tallness given specific constraints or support the development of a dynamic modelling element that interacts with the analysis of density and tallness. In addition, the results of this study suggest that there is no merit to the claim that building denser and taller is more sustainable. By building dense, low-rise urban environments, the same populations can be accommodated for drastically lower carbon costs and without having to significantly increase land use.

Limitations and recommendations

The model limitations are covered in detail in the accompanying Methods section. To capture the stochastic nature of urban areas, a simulation-based methodology is used. A limitation of this approach is that the model selects building types based on the plot size and desired height. Although we checked that, overall, our share of domestic vs. non-domestic building types match that of real urban environments, a fully simulation-based approach could present simulation bias. Further, while we based our input variables selection on extensive data collection of real urban environments (e.g. distance between neighbouring buildings), these input variables could all be subjected to sensitivity analysis to further unravel the extent of the role they play in determining the LCGE of urban environments. An element where this would become particularly useful is to adopt a continuous distribution of buildings' heights to choose from. This would remove the simplification between low-rise and high-rise that we introduce in this research to be able to

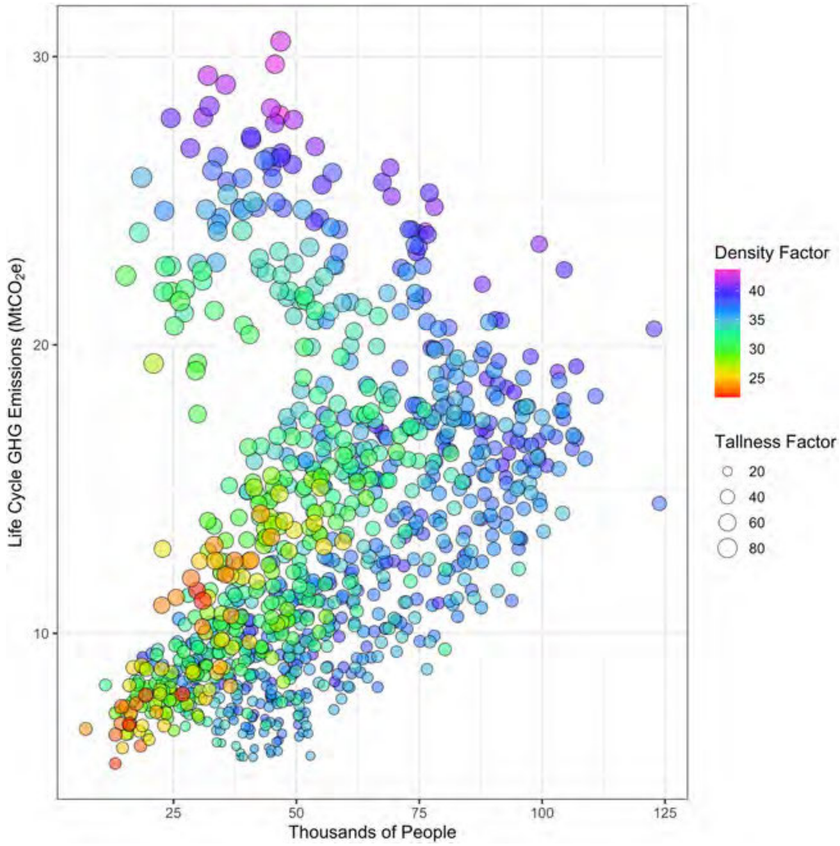
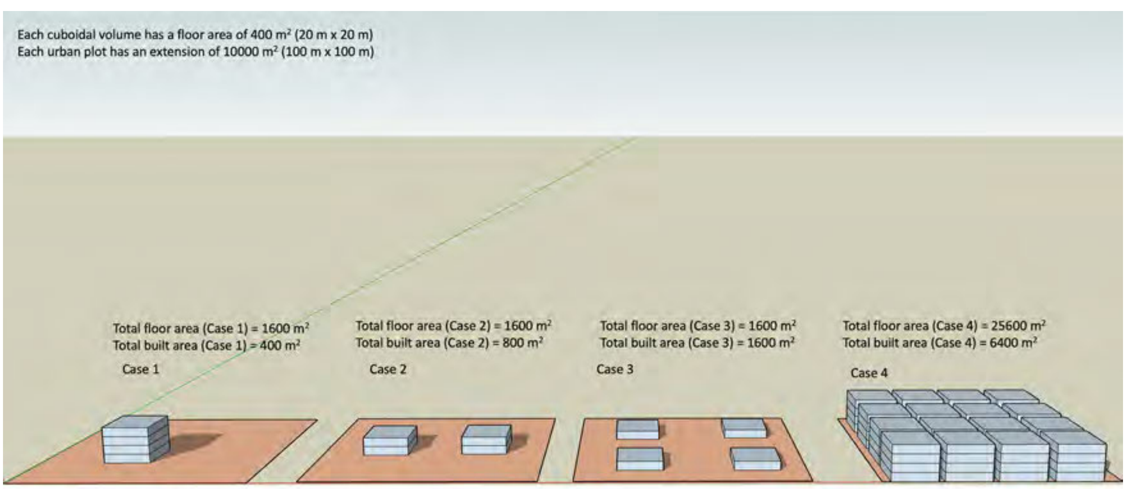


Fig. 5 Density, tallness, and life cycle GHG emissions. LCGE versus number of people accommodated for a fixed land area.



Density approach	Formula	Density (Case 1)	Density (Case 2)	Density (Case 3)	Density (Case 4)
Adopted in this research	$Df = \frac{\sum_{i=1}^{n} A_i}{A_{Land}} * 100$	$\frac{400}{10000} \cdot 100 = 4\%$	$\frac{800}{10000} \cdot 100 = 8\%$	$\frac{1600}{10000} \cdot 100 = 16\%$	$\frac{6400}{10000} \cdot 100 = 64\%$
Existing in the literature (e.g.[15])	$Df' = \frac{\sum_{i=1}^{n} A_i \cdot s_i}{A_{Land}} * 100$	$\frac{1600}{10000} \cdot 100 = 16\%$	$\frac{1600}{10000} \cdot 100 = 16\%$	$\frac{1600}{10000} \cdot 100 = 16\%$	$\frac{25600}{10000} \cdot 100 = 256\%$

Fig. 6 Metrics of urban density. Comparison between floor-area-based metric of urban density and land-occupation based metric (adopted by the authors).

compare the two. Furthermore, to aggregate the embodied GHG emissions values for the substructure and roof, generalisations were made based on average values obtained from literature. Additionally, for land use, land-use change and forestry (LULUCF) we adopt conventionally agreed factors from the leading database ecoinvent. The land use change method adopted and the assumptions of the previous use of land also warrants further research to increase the understanding of the importance of this variable.

These limiting assumptions were necessary based upon the urban scale scope of this study. Providing additional levels of detail at the building scale would greatly improve the accuracy of the analysis and can be refined in future works. Employing a cradle-to-cradle approach to consider resource reuse, the impact of retrofitting existing building stock over rebuilding; the inclusion of transportation impacts; adding a dynamic time component to investigate material inflows and outflows; and including a detailed time-related analysis of carbon sequestration potential offered by urban greeneries in the simulated environments—are all valuable and important avenues for future work to build on this study and expand its relevance while reducing its limitations. This study therefore acts as a stepping-stone to provide a strong foundation from which extensive future work can be born.

When considering LCGE, which encompasses both embodied and operational GHG emissions, the results provide further insight to dispel the growing belief that taller and denser is better. These findings support the growing claim to resolve the unnecessary opposition between embodied versus operational and re-unite them both into the physical unity of a built asset. For example, it has been argued that the environmental impact of the operational phase of cities can be alleviated by green plant coverage, i.e. vegetation façades[29]. However, to support such an additional load there needs to be more materials in the building structure thus increasing the embodied impact. Additionally, vegetation covering the façade may offset carbon emissions, but it also shades the entire façade increasing the need for mechanical means of ventilation, daylighting and heating.

Sustainability is a three-legged stool comprising the economy, the environment and society: to be truly sustainable all three must be in equilibrium. Therefore, interdisciplinary considerations that need to be addressed when progressing this work include, for instance: occupant comfort; the urban heat island effect; competing land use; the carbon sequestration effect of green spaces; urban policies; resource consumption; how the urban environment affects crime; etc. Cities are the central hub of modern society and to address these multi-faceted issues a highly multidisciplinary approach seems the only appropriate way forward.

METHODS

Life cycle assessment methodology

To determine LCGE, carbon coefficients for the different life cycle stages and building components were found from existing literature. Table 1 outlines these results and the embodied and operational carbon coefficients for the five building types considered. A cradle to grave life cycle assessment was conducted for this study, accounting for the 100 year global warming potential (GWP100) measured in kilograms of carbon dioxide equivalent ($kgCO_{2e}$). Here, carbon impact and LCGE are used as shorthand for GWP100. Resource reuse or recycling was excluded since it is beyond the scope of the study. With respect to building components, the core structure, building façade and roof were included while the foundations for all building types were excluded. The lifespan for each building type was assumed to be 60 years, after which the buildings are assumed to be demolished and materials sent to landfill. To accommodate for a decarbonising energy mix, a steady decarbonisation rate of 6.4% per year was applied as this is the rate required to limit global warming to 2 °C[30]. For the models with fixed populations, a land use change factor, 0.08 $kgCO_{2e}$ per m^2, was added to account for the changing land area. This factor was taken from ecoinvent[31] and is specific to construction processes. The focus of this analysis is limited to a UK and European context to reflect the regional variations of lifecycle inventories, which are highly dependent upon the region in which the data is collected[32].

Twenty five case studies were used to generate primary data on the building parameters which were utilised as inputs to the parametric model. Buildings in the UK were chosen to collect primary data due to physical proximity and possibility of accurate measurements and site visits when needed. These collected data were then used to cross check other buildings in Berlin, Oslo, Stockholm and Vienna to make our analysis relevant to the broader Europe (full details in Supplementary Methods 1 and Supplementary Note). To determine the LCGE of the built forms, in $kgCO_{2e}$ per m^2, embodied carbon coefficients (ECCs) for different construction materials and the different life cycle stages were found from existing research and emissions databases[6,31,33–35]. These values were then multiplied by the normalised material intensities found during primary data collection to arrive at the LCGE impact of each building type. Full details are available in Supplementary Methods 3.

The embodied carbon of the façade was calculated from the envelope area and the roof from the building footprint; the ECC of each buildings' structure was taken directly from the literature[36]. The life cycle was considered from Stages A C, cradle to grave, and the operational carbon coefficients were derived from operational energy estimates provided by DECC and DBEIS[37,38].

Parametric model

A bespoke parametric model was developed for this work that allowed the density and height of building plots to be stochastically selected from predefined ranges (Supplementary Methods 2). The ranges were informed by the case studies for the five building types considered in this work. The benefit of this randomisation lies in the variety of realistic built forms that can be developed, computed and assessed. Likewise, block size and street sizes were captured from the case studies. Existing buildings in urban environments were surveyed and data were collected for a number of building characteristics (e.g. population density, storey height, perimeter, building footprint, etc.) and neighbouring constraints (e.g. blocks and green spaces in 1 km^2, road widths, distance from neighbouring buildings, etc.). Full information on the buildings surveyed and data collected for each neighbourhood is given in the supplementary information (Supple mentary Methods 3 and Supplementary Note). Two street sizes were included, main and secondary streets. To calculate the potential population supported by each simulation (for the fixed area case), the floor area per person for each type of building was used. These values are based on the average floor area per person for owner occupied and social housing domestic dwellings (46 m^2 and 36 m^2, respectively)[39] and office space required per person (8 13 m^2)[40].

To simulate the fixed area urban typologies (Scenario 2), 1000 buildings were simulated with random sizes based upon the representative case study buildings for each of the five building types. Next, the land area is divided into blocks with varying dimensions. Main streets were generated between blocks with widths randomly selected from 13, 14 or 16 m, based on the case studies. Each main block is then divided into smaller lots of land based upon the specified density factor which determines the density of the model. Plots that do not have access to streets are turned into green space. Each plot is then iterated over to place a random building with the target tallness factor of the model into each plot. The criteria for placement are that (i) each building has an area of free space surrounding it, (ii) the height of the building is the closest (typically within a five metre range) to the target height factor of the model, and (iii) the space between adjacent buildings is 10 m if high rise whereas low rise buildings can attach to each other. Plots where no representative buildings could fit were turned into green space. Once an urban typology is simulated based on the specified tallness and density factor, the LCGE is computed for that typology. A flowchart to further support the understanding of the logic behind the model is offered in the supplementary material (Supplementary Methods 2).

To simulate the fixed population urban typologies (Scenario 1), 1000 buildings were simulated for each population as described by Scenario 2. A large land area (4×4 km, based on analysis of large urban environments such as London, New York City and Shanghai) was generated and divided into blocks of varying dimensions. Blocks, streets and green spaces are generated in the same manner as Scenario 2, for a 400×400 m grid. The number of possible inhabitants was calculated based on the floor area of the residential buildings divided by the floor area per person required for each building type. Using a recursive algorithm, the initial grid (400×400 m) is increased by 50 m on each side if the number of people is less than the target number of people for the simulation. Buildings are again sampled, and the total population supported recalculated. Once a tolerance of 50 people is achieved, the model calculates the LCGE of the urban typology. The code used to generate this simulation can be accessed through a GitHub repository linked in the Data Availability section.

The carbon impact of green spaces and transport infrastructure were not included as it is beyond the scope of this study. However, a one way

ANOVA was conducted to determine the impact of increasing density on road area. A one way ANOVA was also carried out to determine the impact of building height and density on LCGE, to reduce any uncertainty in the interpretation of the findings. Three hypotheses were tested: (1) Impact of building height on LCGE: H_0 increasing height does not impact LCGE; H_1 increasing height does impact LCGE. (2) Impact of density on LCGE: H_0 increasing density does not impact LCGE; H_1 increasing density does impact LCGE. (3) Impact of density on road area: H_0 increasing density does not impact road area; H_1 increasing density does impact road area. The null hypothesis is rejected for the case of building height; increasing height does significantly impact LCGE. For the case of density and LCGE, the null hypothesis is not rejected; increasing density does not impact LCGE significantly. Likewise, the null hypothesis is not rejected for the impact of road area. The output of each urban typology is the overall density, average height and total LCGE of the stochastic simulation.

Urban density metrics

Urban density is usually referred to as number of people per unit land area inhabiting a given urbanised location. When dealing with urban forms, different approaches exist such as dwellings per hectare or a height centred approach (e.g., floor area divided by land area[15]). The latter can be mathematically represented as follows:

$$Df' \quad \frac{\sum_{i\ 1}^{n} A_i s_i}{A_{\mathrm{Land}}} \tag{1}$$

with the numerator in Eq. (1) above representing total floor space as a sum of products between the building footprint area, A, and number of floors, s, for the generic i^{th} building. The main limitation of such a metric is that it does not allow to differentiate between the separate effects resulting from horizontal and vertical densifications. This is graphically illustrated in Fig. 6 where three urban configurations (Cases 1, 2 and 3) score the same urban density (16% as per Eq. (1)); however, they are significantly different if we look at them in terms of land occupation and vertical development. Two separate metrics are therefore required in order to estimate the effect of these two parameters independently. Specifically, we developed two distinct factors for density and height, a "density factor" (*Df*) and a "tallness factor" (*Tf*), as defined in equations (2) and (3), where A_i is the building footprint of the generic building i, A_{Land} is the useable land area, H_i is the building height of the generic building i and n is the number of all buildings.

$$Df \quad \frac{\sum_{i\ 1}^{n} A_i}{A_{\mathrm{Land}}} \tag{2}$$

$$Tf \quad \frac{\sum_{i\ 1}^{n} H_i}{n} \tag{3}$$

Using the two density factors in Eqs. (2) and (3) above allow for an independent evaluation of the effects that horizontal densification (occupying more of the available land) and vertical densification (building taller) have on urban environments. When density and height are combined, for example expressing density as a function of floor area (e.g. Eq. (1)), two scenarios can have identical urban densities but completely different typologies, thus masking the impact of building type.

Additionally, the density factor we developed always ranges between 0 and 1 (or 100%), thus enabling meaningful comparisons within strict and defined boundaries. The existing metric instead allows density values to exceed 100% (Case 4 in Fig. 6) and potentially has no theoretical upper bound thus limiting further its practical use in comparing the density of different urban typologies.

DATA AVAILABILITY

The data generated and analysed during this study are described in the following data record: https://doi.org/10.6084/m9.figshare.14663313[41]. All code and supporting data can be accessed via GitHub at https://github.com/jayarehart/Denser Taller. Static versions of the two data files included in the GitHub repository have also been included with the figshare data record[41] (downloaded from GitHub on 24/05/2021). Additional supplementary data and notes are available in the files 'supplementar y methods.xlsx' (Excel spreadsheet with multiple tabs) and 'supplementary notes. pdf', which are publicly available in the Mendeley Data repository at https://doi.org/10.17632/kj3zn5nx6b.1[42], as well as together with this figshare data record[41].

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AUTHOR CONTRIBUTIONS

F.P. and B.D. conceptualised the research. R.S. conducted the primary data collection and N.G. developed the parametric model. R.S., N.G. and J.A. developed the methods and performed the analysis. All authors contributed to the discussion and interpretation of the results. F.P., R.S. and J.A. wrote the manuscript and SI. All authors reviewed and edited the manuscript and approved the final version.

COMPETING INTERESTS

The authors declare no competing interests.

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BRITISH COLUMBIA BUILDING PERFORMANCE STUDY

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December 2014

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Light House Sustainable Building Centre

EXECUTIVE SUMMARY

British Columbia's existing buildings account for two-thirds of all energy consumed in the Province and 41% of the Province's total GHG emissions. Recognizing the significant role that buildings play in meeting the Province's efforts to address climate change, energy, and water consumption and waste generation, this study sought to evaluate the performance of buildings in British Columbia and provide special consideration to the potential impact of third-party rating systems on achieving public policy objectives.

The study reviewed energy consumption data for 337 buildings from across the Province, including 147 BOMA BESt certified buildings and 190 non-certified buildings. The majority of certified buildings were office buildings (121), followed by retail (19), multi-unit residential (5) and industrial (2).[1] In contrast, the vast majority of non-certified buildings were multi-unit residential buildings (110), followed by office (54), hotels (19), retail (5) and other buildings (2). A further breakdown of the sample set is detailed in section 3 of the report.

KEY FINDINGS

General

- Bringing the bottom quartile of office buildings and MURBs in the study up to the median EUI for the respective building types would result in a reduction of 5% of total energy consumption in British Columbia.
- Extreme variations in energy use intensity, water use intensity, and waste exist across buildings.

Office Buildings

- The average site energy use intensity (EUI) for all office buildings in the study was 319 kWh/m^2/yr, 17% higher than the NRCan benchmark for buildings in BC and the Territories. The top 25^h percentile had an average EUI of 243 kWh/m^2/yr compared with 372 kWh/m^2/yr for the bottom quartile.
- Bringing the bottom quartile of office buildings up to the median EUI for all office buildings in the study would result in a potential reduction of 5% of total energy consumption by all office buildings in the Province.
- The average water use intensity of all office buildings in the study was 1.32 m^3/m^2/yr, significantly higher than both comparative benchmarks (0.91 and 0.642 m^3/m^2/yr), with the bottom quartile of buildings exhibiting values exceeding 1.90 m^3/m^2.
- The average waste diversion rate for office buildings was 59% and the median 55%, below targets set by the Province and regional governments.
- Newer office buildings showed a slight reduction in GHG emission intensities.
- GHG emission intensity was positively correlated with the number of floors in office buildings. The greater the number of floors the higher the relative GHG emission intensity.

[1] BOMA BESt only introduced a certification for multi-unit residential buildings in 2012, which accounts for why there were only five such buildings in the study.

Multi-Unit Residential Buildings

- The average site EUI for all MURBs was 215 kWh/m^2/yr, much better than benchmarks in other comparative studies[2], with the top quartile achieving an average site EUI of 153 kWh/m^2/yr and the bottom quartile averaging 259 kWh/m^2/yr.
- In contrast to other studies, there was a slight negative correlation between building age and energy performance for MURBs, although tentative given the relative age distribution of buildings in the study.
- The energy performance of low-rise MURBs was 28% better than mid-rise MURBs and 22% better than high-rise MURBs.
- GHG emission intensity values mirrored energy use intensity levels.

BOMA BESt Certification

- BOMA BESt office buildings that recertified showed a 25% improvement in energy use intensity (EUI) over buildings that had only gone through the original certification process. Similarly, recertified buildings achieved a 30% reduction in annual building water usage per square meter of space and an average increase of 8% in diverted waste.
- BOMA BESt attracts all types of buildings and performers and is a useful tool not just for high performing buildings but is being used by many lower performing buildings as a means to start benchmarking environmental performance and work towards continual environmental improvement.
- Extrapolating findings with respect to BOMA BESt to LEED EB:O&M was not possible given the study's scope. A more detailed credit-level analysis of both rating systems is required to assess equivalencies between the two frameworks.
- Level 4 BOMA BESt buildings were the best performing buildings in the study;
- Almost all BOMA BESt buildings had some form of energy management policy (99.3%)
- Just over half (55%) of certified buildings were conducting waste audits every three years.

With respect to BOMA BESt, it must be stressed that certification is based on pre-certification data and serves as an exercise in benchmarking a building. First-time certification is not an indicator of performance improvement, but rather a tool to help building owners and managers benchmark and work towards continual improvements in environmental performance.

The study's findings indicate that there is significant room for improvement in most aspects of building performance across all building types. Findings also indicate that the act of recertifying is strongly associated with improvements in building performance.

[2] See Appendix A for summary of findings from benchmark studies by RDH and Fresco.

The study presents the following key policy recommendations coming out of the report's findings and the process undertaken to complete the report[3]:

1. Improve access to energy consumption data from utilities.
2. Mandate reporting of building energy, waste and water data.
3. Incentivize and/or mandate auditing and retro-commissioning of all buildings.
4. Consider rating systems at the credit level to achieve policy objectives.
5. Focus efforts and support on Class B and C office buildings and residential buildings.

[3] The recommendations provided in this report are those of Light House and the report's authors and do not necessarily reflect the views and positions of the study's partnering and sponsoring organizations.

EXECUTIVE SUMMARY

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1. INTRODUCTION

1.1. Context

In the face of mounting focus on energy efficiency and climate change, provincial and municipal governments are seeking effective options for achieving significant reductions in energy consumption and GHG emissions, as well as reductions in water consumption and waste production. Within the Province of British Columbia, data reported by local governments in Community Energy and Emission Inventory Reports indicate that BC's existing buildings account for two-thirds of all energy consumed in the Province, more than half of which in turn comes from residential, commercial and small-medium size industrial buildings (see Figure **1**).[4] These same buildings account for 41% of the Province's total GHG emissions (see Figure **2**). Focusing attention on the performance of existing buildings is therefore a worthwhile effort from a resource savings perspective, not to mention the associated benefits in terms of cost savings, job creation, tenant comfort, and reduced pressure on energy infrastructure.

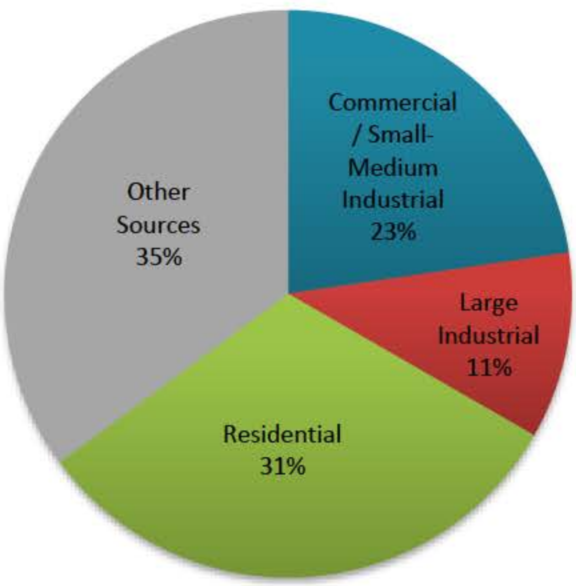


Figure 1: Energy Consumption by Buildings in British Columbia

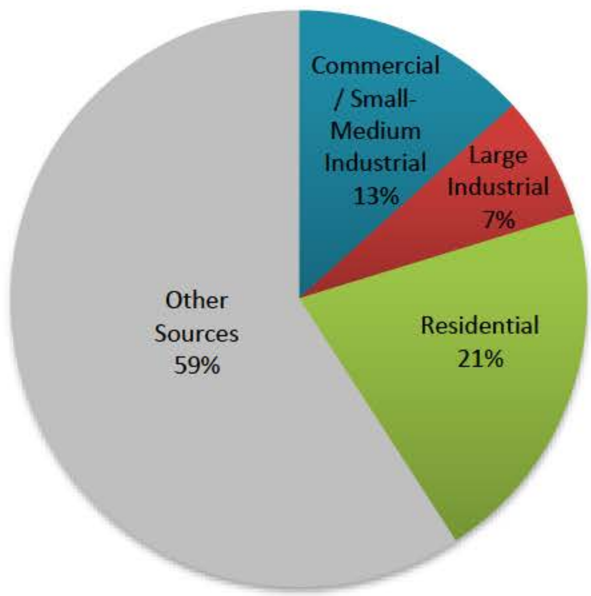


Figure 2: GHG Emissions from Buildings in British Columbia

One of the most significant barriers facing the development of effective policies and programs to improve building performance is the serious lack of energy, waste and water data for buildings in British Columbia. Meaningful data is essential to inform the development of strategies that support improvements in building performance and help meet public sustainability objectives with respect to GHG emissions, energy, waste and water.

[4] Total energy consumption reported for all buildings in British Columbia is 1.069 billion GJ or 297 billion kWh. Source: 2010 CEEI dataset as of January 23, 2013 available at http://www.env.gov.bc.ca/cas/mitigation/ceei/reports.html.

At the same time, industry has responded by developing green building rating systems (e.g., BOMA Building Environmental Standards (BOMA BESt) and Leadership in Energy and Environmental Design (LEED)) to benchmark and improve the performance of new and existing buildings (see section 5.2 of this report for a detailed description of both rating systems). Governments at all levels across North America have either adopted or are contemplating the adoption of policies encouraging or regulating partial or full compliance with third-party green building rating systems, specifically ordinances and bylaws requiring new construction to meet a prescribed certification level under LEED and more recently Green Globes (the platform on which BOMA BESt was developed). For example the US government has recently required all new federal buildings to be certified under LEED since 2003 (LEED Gold since 2010) and just recently recognized Green Globes as well.[5] However, there has been no analysis undertaken to determine the extent to which these third-party rating systems support green building policy objectives, such as GHG emission reduction.

1.2. Study Objectives

The purpose of this study is to evaluate the performance of buildings in British Columbia and consider the potential impact of third-party rating systems on achieving public policy objectives. The extent to which third-party rating systems can support public policy objectives for existing buildings has been given limited consideration in the past. This report aims to address this analytical gap, by answering the following questions in the BC context:

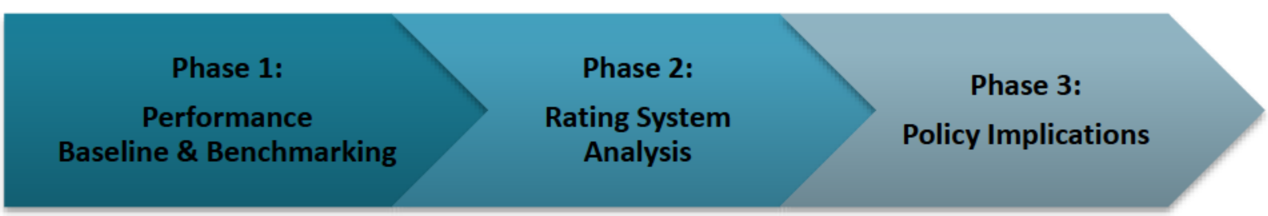
1. What is the state of building performance in British Columbia and how does building performance correlate with various building characteristics, such as age, type, size and location.

2. Can third-party certification systems for existing buildings help governments in BC to meet their green building and related policy objectives?

3. If the answer to #2 is yes, then what else can / should governments in BC do to require / encourage / incentivize the pursuit of third-party certification systems for existing buildings?

To address these questions the study reviewed environmental performance data for 337 buildings from across the Province, including 147 BOMA BESt certified buildings and 190 non-certified[6] buildings.

The study was divided into three phases intended to provide a more comprehensive understanding of actual building performance, and the role of industry standards and public policy in achieving building performance targets.



[5] Sustainablebusiness.com, "Industry-Friendly Green Building Standard Wins Big" (October 28, 2013).
[6] "Non-certified" buildings refer to existing buildings that were not certified under BOMA BESt. Three of the non-certified buildings in the study sample had been certified under LEED for New Construction at the time they were built. It was determined that these buildings could be included in the study because LEED NC 2009 did not consider actual building performance and it is generally accepted that energy modeling is not a reliable indicator of a building's actual energy performance.

Phase 1 of the study sought to establish baseline performance data for buildings across BC. Building performance data on energy, waste and water was obtained for 147 BOMA BESt certified and 190 non-certified buildings. This data was then analyzed and compared against other relevant and available performance benchmarks.

The central objective of phase 2 was to evaluate the ability of third-party green building rating systems to meet public policy objectives around energy conservation, water conservation and waste diversion and reduction. In addition, phase 2 also sought to assess the degree of alignment between LEED for Existing Buildings Operations & Management (LEED EB:O&M)[7] and BOMA BESt and through that process, speculate on the potential impact that both systems could have on building performance. The presumption being that if there was a high degree of alignment, then LEED EB:O&M buildings would be expected to perform comparable to BOMA BESt certified buildings. Work comprised a series of interviews with property managers of recertified buildings, a credit-level analysis of BOMA BESt points to identify which points yielded the greatest performance gains at the least cost and a credit-level comparison of both rating systems. This approach was taken because the limited number of buildings certified under LEED EB:O&M at the time of the study made it impossible to undertake a direct comparison of performance data between LEED EB:O&M certified, BOMA BESt certified and non-certified buildings. The findings were used to consider the degree to which both rating systems could support public policy objectives with respect to building performance and sustainability more broadly.

Finally, phase 3 considered the implications of the findings from phase 1 and 2 on green building policy and the role of third-party rating systems in advancing green building and sustainability objectives identified by the Province.

7 The hypothesis being that if the energy related components of both rating systems are equivalent, one can expect that building performance for a LEED EB:O&M building to be equivalent to a BOMA BESt certified building. While it is recognized that this approach has its limitations, the assessment is important from a policy development perspective as governments seek to determine which, if any, rating system will support its energy performance objectives for buildings.

2. METHODOLOGY

The study employed an extensive and rigorous effort to collect and analyze performance data from buildings across British Columbia. Steps taken during the study are detailed below.

TASK 1: Assembled BOMA BESt Building Data

The first step was to assemble building performance data for BOMA BESt certified buildings. At the time the study was undertaken, there were 246 buildings certified under BOMA BESt in British Columbia. Table 1 provides a breakdown of all BOMA BESt certified buildings in the Province by city.

Table 1: BOMA BESt Certified Buildings in British Columbia by City

City	Level 1	Level 2	Level 3	Level 4	Sub-Total
Vancouver	26	31	30	3	90
Burnaby	18	39	4	1	62
Richmond	6	11	5	0	22
North Vancouver	1	6	2	0	9
New Westminster	2	0	0	0	2
Surrey	0	1	0	0	1
Delta	2	0	0	0	2
Port Moody	1	0	0	0	1
Langley	2	1	1	0	4
Coquitlam	0	0	2	0	2
Pitt Meadows	0	0	1	0	1
Maple Ridge	0	0	1	0	1
Victoria	6	13	5	0	24
Nanaimo	0	1	1	0	2
Courtenay	1	2	0	0	3
Kamloops	0	1	2	0	3
Prince George	0	3	0	0	3
Terrace	0	1	0	0	1
Fort St. John	0	1	0	0	1
Abbotsford	1	0	1	0	2
Chilliwack	1	0	0	0	1
Cranbrook	1	0	0	0	1
Kelowna	1	0	1	0	2
Langford	2	2	0	0	4
Vernon	0	0	1	0	1
Port Alberni	0	1	0	0	1
Total	71	114	57	4	246

Performance data from 2009 to 2013 for Level 2,3 and 4 certified buildings was provided by BOMA BC from their online assessment database. Of these buildings, six were missing energy data and an additional 22 were missing gas/steam data leaving147 BOMA BESt buildings with complete energy data.

BOMA BESt level 1 certified buildings were excluded from the study sample because they are not required to submit detailed performance data and to be consistent with the approach taken by BOMA Canada in its reporting on the performance of BOMA BESt certified buildings across Canada.[8] As an aside, partial energy data was available for 37 of the 71 level 1 certified buildings, however 14 of these were missing gas data and 2 were missing electric data, leaving 21 level 1 certified buildings with complete energy data.

The remaining 147 BOMA BESt certified buildings were segmented according to BOMA's building type classifications, including Offices, Enclosed Shopping Centres, Open Air Retail, Light Industrial, and Multi-Unit Residential Buildings.[9]

TASK 2: Assembled Non-Certified Building Data

Building owners and property managers from across British Columbia were approached to have their buildings participate in the study. Those who agreed to participate were offered three methods of providing energy data for whole buildings:

(1) By providing utility data or receipts for a 12-month period or alternatively, signing a permission form authorizing BC Hydro and Fortis BC to release their utility consumption data;
(2) Through BOMA BESt report cards self-reported by building owners; and
(3) From BC Hydro and Fortis BC online billing statements with access provided by the building owner.

Despite significant efforts, Fortis BC was unable to provide gas utility data for approximately 200 buildings that provided signed authorization forms under option 1. Natural gas consumption data for 51 of these buildings was ultimately gathered manually or through online billing records. However, 149 buildings that had initially offered to participate were ultimately left out of the study because neither Fortis BC nor the owners of these buildings were able to provide amalgamated gas data.

Buildings that were not able to confirm both electric and gas utility data or confirm that the building only used electricity were also excluded, resulting in the removal of an additional 66 buildings from the data set:

- 15 BOMA BESt buildings (3 retail, 1 industrial, and 10 office buildings) which could not confirm if the buildings used and reported steam or natural gas use for heating or domestic hot water;
- 31 multi-unit residential buildings from one property manager who could not confirm if the buildings had natural gas meters for heating or domestic hot water; and
- 20 buildings (3 MURBs, 5 industrial, and 11 offices) from another property manager that could also not confirm if the buildings used natural gas for heating or domestic hot water.

MURB data represented whole building data, including tenant data. Electricity data for most of the 110 non-certified MURBs in the study was obtained from BC Hydro, while building owners provided

[8] BOMA Canada, *BOMA BESt Energy and Environment Report 2013*. Available at http://www.bomabest.com/wp-content/uploads/BBEER-2013-Full-Report.pdf.
[9] See *BOMA BESt Version 2 Content: Module Definitions and Performance Benchmarks* for definitions of building typologies at http://www.bomabest.com/wp-content/uploads/Module-Definitions-and-Performance-Benchmarks.pdf. Accessed May 24, 2013.

the gas data. In some instances, owners provided both electricity and gas data. This data was cross-checked for reasonableness (i.e., was the data a reasonable reflection of the energy consumption for a building of that size or more representative of a single tenant's utility bill.) BC Housing building stock represented 65% of the buildings in the MURB sample with the rest of the sample coming from six other owners.

In addition, participants were asked to voluntarily complete an online survey on their water and waste consumption and environmental practices. Most participants were only able to provide energy data and opted not to complete the online survey. Consequently, very limited waste and water data was available for non-certified buildings in the study sample.

The key performance indicators requested for this study and their sources are set out in Table 2 below:

Table 2: Building Performance Indicators and Data Sources

Indicator (Unit of Measure)	Data Required	
	BOMA BESt Data set	non-BOMA BESt Data Set*
Energy & Carbon		
Total Annual Energy Use Per Building* (kWh)	BOMA BC	(PF and U) or S
Energy Use Intensity (EUI) Per Building (kWh/m²)	BOMA BC	(PF and U) or S plus M, GE, and/or BCA
Total Onsite Annual Electricity Generation Per Building (kWh)	BOMA BC	S
Annual GHG Emissions Per Building (tonnes eC0₂/y)	BOMA BC	(PF and U) or S
GHG Emissions Intensity Per Building (tonnes eCO₂/m²)	BOMA BC	(PF and U) or S plus M, GE, and/or BCA
Green Energy Purchased (Y/N)	BOMA BC	S
Energy Policy / Mgmt. Plan (Y/N)	BOMA BC	S
Energy Audit Completed within last 3 years (Y/N)	BOMA BC	S
Energy Training Program ((F)ormal, (I)nformal, N)	BOMA BC	S
Lighting Types (qualitative)	BOMA BC	S
Major HVAC Equipment (qualitative)	BOMA BC	S
Controls (qualitative)	BOMA BC	S
Hot Water System (qualitative)	BOMA BC	S
Financial		
Annual Energy Costs Per Building ($)	BOMA BC	(PF and U) or S
Normalized Energy Costs Per Building ($/m²)	BOMA BC	(PF and U) or S plus M, GE, and/or BCA
Annual Water Costs Per Building ($)	BOMA BC	S or M
Normalized Water Costs Per Building ($/m²)	BOMA BC	S, MGE or BCA
Annual Solid Waste Management Costs Per Building ($)	BOMA BC	S
Normalized Solid Waste Management Costs Per Building ($/m²)	BOMA BC	S plus M, GE and/or BCA
Planned expenditures for energy efficiency for the 5 years following certification / current year ($)	BOMA BC	S
Green Leases with Tenants (Y/N)	BOMA BC	S
Water & Waste		
Total Annual Water Consumption Per Building (m³)	BOMA BC	S or M
Normalized Water Consumption Per Building (m³/m²)	BOMA BC	S or M, plus M,GE and/or BCA
Water Conservation Features (qualitative)	BOMA BC	S
Water Audit Completed in Last 3 Years	BOMA BC	S

% Waste Diverted from Landfill Per Building	BOMA BC	S
Written Waste Management Policy (Y/N)	BOMA BC	S
Waste Audit Completed in Last 3 Years (Y/N)	BOMA BC	S
Refrigerant Management Plan (Y/N)	BOMA BC	S
ODS Phase Out Plan (Y/N)	BOMA BC	S
Green Cleaning Purchasing Policy (Y/N)	BOMA BC	S
Building / Site Characteristics		
Height (Low, Mid, High)	BOMA BC	S or M or BCA
Type (Small / Large Office, Institutional, Retail, Multi-Unit Residential, Industrial)	BOMA BC	S or M or BCA
Year Built	BOMA BC	S or M or BCA
Year Major Renovations	BOMA BC	S or M or BCA
Green Building Certifications (BOMA BESt Level, LEED-NC, LEED-EB: O&M, Other)	BOMA BC, research	S, research
Documented Environmental Policy / Mgmt. Plan (Y/N)	BOMA BC	S
Construction Method (concrete, wood frame)	BOMA BC	S or MGE or BCA
Number of Occupants / Users	BOMA BC (v.2)	S
Envelope (qualitative)	BOMA BC	S
Documented Operating Instructions (Y/N)	BOMA BC	S
Access to Public Transportation (qualitative)	BOMA BC	S
Bike Racks for > 5% of occupants (Y/N)	BOMA BC	S
LID Stormwater Management (qualitative)	BOMA BC	S

*Notes

1. Neither BOMA BESt nor utility data will allow for the distinction between energy used for particular uses, such as space heating, lighting, or domestic hot water. More detailed building inspections, energy modeling, and other building specific technical work far beyond the scope of this study would be required to break down energy use in this manner.
2. BOMA BESt baseline indicators will be calculated for the year in which the buildings were certified. BOMA BESt buildings are required to recertify every 3 years. For those buildings (17 as of Sep 2012), changes from the baseline will also be calculated.
3. Data Sources for Non-BOMA BESt Buildings:
   U: Utility data: Natural gas and electrical consumption data provided by utility companies by building.
   M: Municipalities: Data provided from municipalities, namely building footprint or area, building type, building construction type and year built plus water consumption.
   GE: Google® Earth: Manual analysis of Google® Earth data on buildings to calculate number of building storeys and possibly construction type.
   BCA: BC Assessment Authority: Where municipalities cannot provide the required data, BC Assessment data will be queried to determine building footprint or area, and building type.
   PF: Utility Data Permission Forms: Permissions forms signed by participating building owners or managers to have utilities release building energy data.
   S: Electronic survey completed by participating non-BOMA BESt building owners or property managers

Following the approach taken by one of the City of New York's review teams in its 2012 Benchmarking Report[10], the building data underwent extensive "cleaning", including the elimination of buildings with unreasonably high and low energy usage intensities. A total of ten buildings (3 MURBs, 1 office, 3 retail, and 3 industrial) were excluded from the study that reported energy use intensity values of less than 15.8 ekWh/m^2/yr or more than 2,050 ekWh/m^2/yr.

TASK 3: Entered Building Data into ENERGY STAR Portfolio Manager®

All buildings were assigned a unique identification code and monthly performance data was entered confidentially into ENERGY STAR Portfolio Manager®[11] to generate site energy use

[10] See Plan NYC, New York City Local Law 84 Benchmarking Report (August 2012) at pg. 30. Available at http://www.nyc.gov/html/gbee/downloads/pdf/nyc_ll84_benchmarking_report_2012.pdf. The New York City benchmarking report was referenced solely to assist in formulating this study's methodology. Its findings were not used as a basis for comparison with the outcomes of this study.

[11] ENERGY STAR Portfolio Manager® is an energy benchmarking software widely used in the United States and now available in Canada for benchmarking buildings energy use. The software automatically compares and normalizes building energy usage based on building location, number of occupants, vacancy rates, hours of operation and type of usage. Portfolio Manager® is most commonly used as a tool to normalize building energy data for the variables discussed above, it is also used to generate an ENERGY STAR score for how well a building is performing in terms of energy usage compared to similar buildings. An ENERGY STAR rating is a number between 0 – 100 which indicates which percentile a building is performing in compared to its peers in terms of energy consumption. For

intensity (site EUI) and total GHG emission intensity for all buildings, as well as ENERGY STAR scores for offices only.

In calculating site EUI and GHG emission intensity, Portfolio Manager® normalizes building data to account for a variety of variables, including climate, weather, occupancy, hours of operation, number of computers, percentage of space heated and cooled and number of fridges and freezers.[12] Unless directly provided by the owner and/or received from the BOMA BESt report card, default values provided by Portfolio Manager® were used for these variables (see Table 3 for a summary of Portfolio Manager® defaults). Normalization of the study data resulted in a change in Site EUI values between -0.55% and +1.54% from non-normalized values. While comparable energy benchmarks (e.g., NRCan) do not normalize energy data, the nominal impact of normalizing the data in this instance was not considered significant enough to preclude comparisons with other referenced energy benchmarks. The authors foresee the use of Portfolio Manager® and the normalizing of building data for weather and other factors to become standard practice in future benchmarking studies and industry reporting.

Table 3: Default values used in Portfolio Manager®

Indicator	Default Values
Weekly Operating Hours	Retail & Office: 65 hours Warehouse: 60 hours
Workers on Main Shift	Office: 2.3 workers/1,000 ft^2 Retail: 1 worker/1,000 ft^2 Warehouse: 0.59/1,000 ft^2
Number of PCs	Office: 2.2 PCs/1,000 ft^2 Retail: 0.2 PCs /1,000 ft^2
Percent Heated/Air Conditioned	Office: 50% or more Retail: 100 Multifamily: 100 Unrefrigerated Warehouse: 50% Heated/ 20% AC
Number of cash registers	Retail: 0.3 per 1,000 ft^2
Walk-In Refrigeration/ Freezer Units	Retail: 0 unit Unrefrigerated Warehouse: 0 unit
Open & Closed Refrigeration/Freezer Cases	Retail: 0 unit
Exterior Entrance to the Public	Retail: Yes

TASK 4: Analyzed Building Performance Data

Data for both certified and non-certified buildings was amalgamated and compared against the identified benchmarks. The study adopted a number of existing energy, waste and water

example a score of 75 indicates the buildings is in the top 25 percent of all similar typology buildings. As of October 2013, ENERGY STAR scores were only available for office buildings and K-12 schools in Canada.

[12] *See* ENERGY STAR Portfolio Manager®, *Technical Reference on Climate and Weather* (July 2013) at https://portfoliomanager.energystar.gov/pdf/reference/Climate%20and%20Weather.pdf. Portfolio Manager data is normalized against itself (building level) for weather and occupancy. In contrast, ENERGY STAR scores are normalized relative to similar buildings from different locations (i.e., a building in Prince George will report a higher site EUI than a similar building in Vancouver, however they could have the same ENERGY STAR score once climate variations are taken into account.)

benchmarks for comparison purposes (see discussion of benchmarks in Appendix B below). Benchmarks cited throughout the study are provided for the purposes of comparison, recognizing that each is context specific and subject to its own limitations. In specific, energy benchmarks from other studies did not use Portfolio Manager® to normalize their data.

Performance data was analyzed in relation to building age, square footage, number of floors, building class, climatic zone and Level of certification where applicable. Despite efforts to provide a balanced sample of certified and non-certified buildings, the study had a disproportionate number of certified office buildings and non-certified MURBs. The unequal representation of certified and non-certified buildings is shortcoming of the study and identified as a challenge throughout the report. As a result, the study focused primarily on analyzing building performance generally with minimal attention to the distinction between certified and non-certified buildings. Caution should be exercised in using the study's findings to compare the performance of certified and non-certified buildings.

BOMA BESt certification requires the submission of 12 months of data prior to certification. Buildings are not required to provide performance data post-certification. Consequently, in most instances the study was not able to compare the performance of buildings pre- and post-certification. The question of whether certification does support improvement in building performance was addressed to a limited extent by considering the performance of buildings that had recertified under BOMA BESt. Of the 147 BOMA BESt buildings in the study sample, seven were identified as having a corresponding recertification numbers (i.e., the buildings had applied for recertification). An additional 15 recertified buildings were manually correlated using building names and addresses for a total of 22 recertified buildings. Additional research on this question would is encouraged.

Unfortunately, at the time of the study only 3 buildings had been certified in British Columbia under LEED EB:O&M. Consequently, no direct comparisons could be made between LEED EB:O&M and BOMA BESt certified buildings, or between LEED EB:O&M certified and non-certified buildings. Further study in this area is recommended as more existing buildings are certified under LEED EB:O&M.

TASK 5: Aligned Rating Systems with Public Policy Objectives

The first step in assessing the alignment of third-party rating systems with public policy objectives was to complete a scan of public policy targets with respect to GHG, energy, waste and water at both the community and building level. BOMA BESt was reviewed and each credit was grouped under its appropriate policy objective (e.g. energy reduction and credit for energy audits). Credits under LEED EB:O&M were similarly assigned to the appropriate policy objective. Each Credit requirements under each rating system were then analyzed to determine their degree of comparability, as well as their alignment with policy objectives. Finally, credit uptake values were obtained from BOMA Canada and the Canada Green Building Council to determine the popularity of various credits. All of this amassed in a matrix detailed in Appendix C of this report.

The matrix was then analyzed to assess the degree of comparability between rating systems, alignment of specific credits with public policy objectives, and the degree of uptake. Study findings associated with BOMA BESt credits were extended to LEED EB:O&M credits that demonstrated a high degree of comparability. Credits that showed a high degree of alignment with policy objectives were identified and associated performance enhancements identified where possible. Credit uptake levels were then considered in relation to these credits to determine whether voluntary compliance was sufficient to support public policy objectives.

3. THE BUILDINGS

The 337 buildings included in this study, including 147 BOMA BESt certified buildings and 190 non-BOMA BESt buildings, represent 46.2 million square feet (4.3 million square metres) of real estate from across British Columbia (see Figure 3).

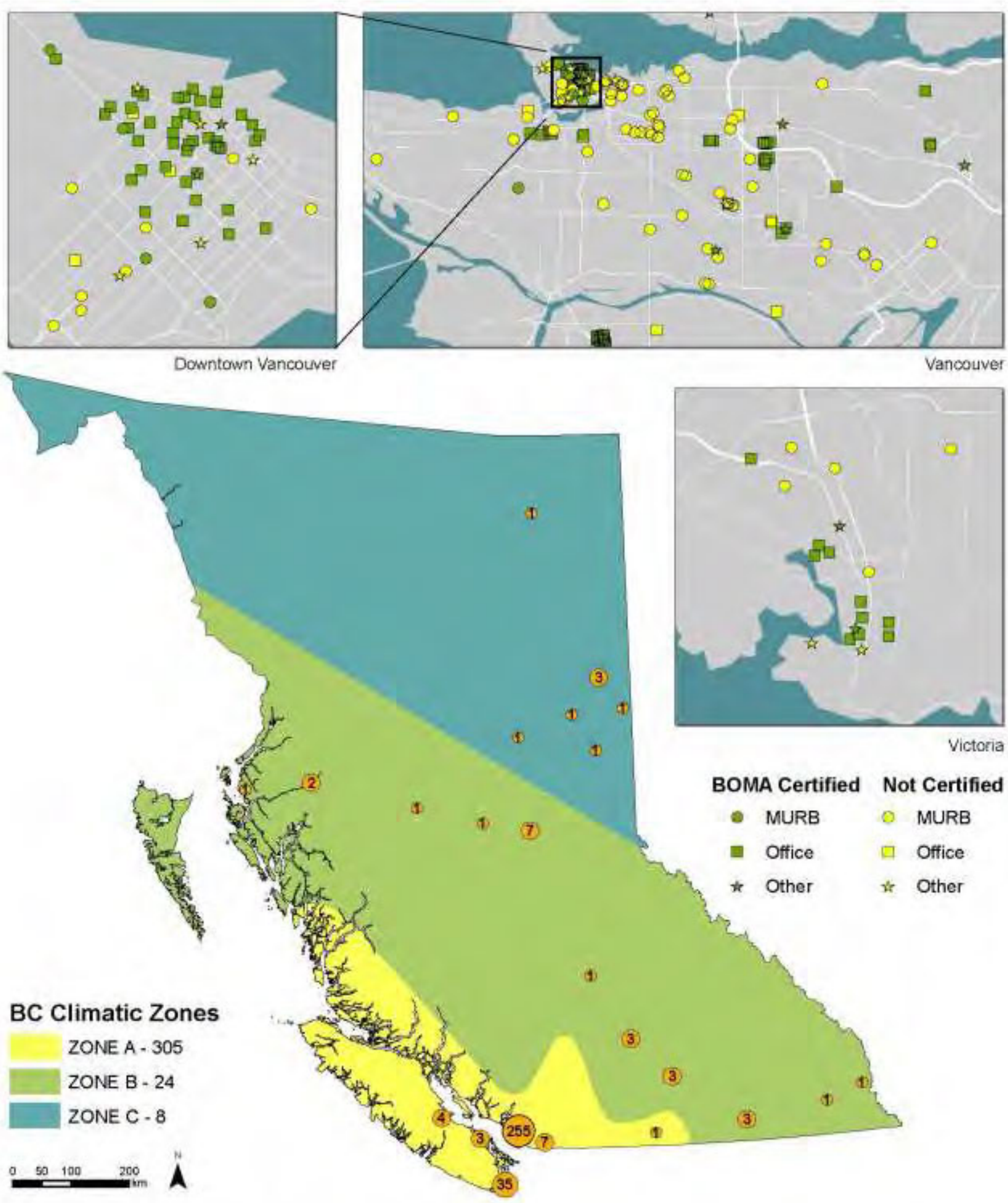
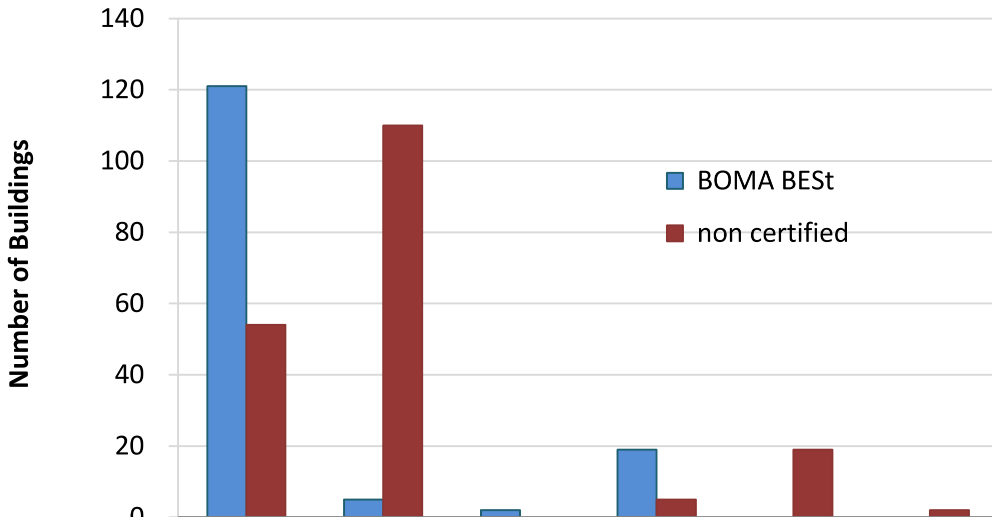


Figure 3: Distribution of Sample Buildings in Study

The majority of buildings in the study were classified as office and multi-unit residential buildings. Extensive efforts were made to identify equal numbers of BOMA BESt certified and non-certified buildings for each building type, however the sample ultimately contained a disproportionate number of BOMA BESt certified office buildings and an equally disproportionate number of non-certified MURBs.[13] The majority of certified buildings were office buildings (121), followed by retail (19), multi-unit residential (5) and industrial (2).[14] In contrast, the vast majority of non-certified buildings were multi-unit residential buildings (110), followed by office (54), hotels (19), retail (5) and other buildings (2). Table 4 provides the distribution of BOMA BESt certified and non-certified buildings in the study sample. The relatively small number of retail, hotel and industrial buildings, prevented independent consideration of these typologies. Caution should be exercised in extending the findings for office and MURBs to these other building types.



	Office	MURB	Industrial	Retail	Hotel	Other*
BOMA BESt	121	5	2	19	0	0
non certified	54	110	0	5	19	2

* The two “Other” buildings in the sample were community centres.

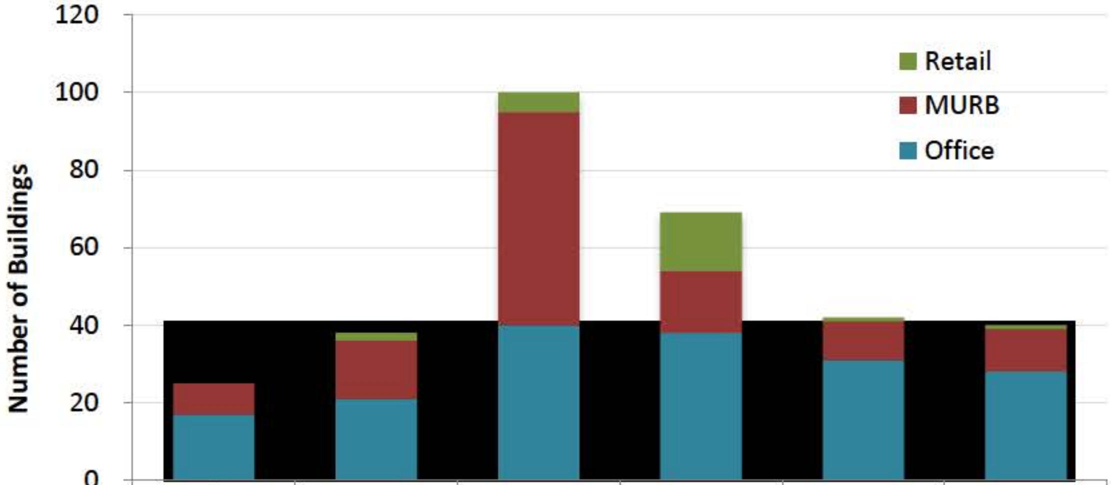
Table 4: Distribution of BOMA BESt certified and non-certified buildings by building type

3.1. Building Age

Buildings ranged in age with the highest proportion built in the 1970s. The majority of office buildings and multi-unit residential buildings were both constructed in the 1970s and 1980s. The oldest MURB in the study was from 1894 and the oldest office building is from 1973. Table 5 summarizes the breakdown of buildings by age.

[13] The lack of office buildings in the non-BOMA BESt building is attr butable to149 office buildings being excluded from the study due to the inability to obtain natural gas data from Fortis BC. Obtaining utility data from building owners was equally difficult to obtain. Many challenges were encountered in the course of trying to obtain data and running quality control on available data.

[14] BOMA BESt only introduced a certification for multi-unit residential buildings in 2012, which accounts for why there were only five such buildings in the study.



	Before 1960	1960-1970	1971-1980	1981-1990	1991-2000	2001-2012
Retail	0	2	5	15	1	1
MURB	8	15	55	16	10	11
Office	17	21	40	38	31	28

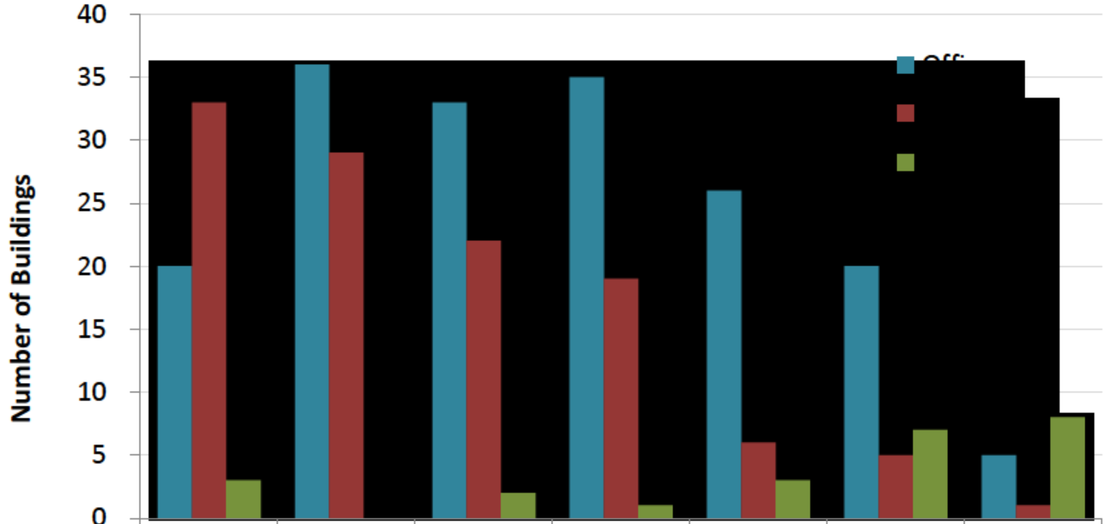
Year Built

Table 5: Distribution of buildings by age

Again, the small number of industrial, retail and hotel buildings in the study prevented comparisons of these building types based on age.

3.2. Floor Area

The distribution of buildings in the sample was representative of current building inventory with a bell shape distribution for office buildings and a majority of MURBs under 150,000 ft^2 (see Table 6).



	0-25,000	25,000-50,000	50,000-100,000	100,000-150,000	150,000-250,000	250,000-500,000	over 500,000
Office	20	36	33	35	26	20	5
MURB	33	29	22	19	6	5	1
Retail	3	0	2	1	3	7	8

Size (ft^2)

Table 6: Building Distribution by Size

3.3. Building Class

Office buildings are grouped into three classes providing the market with a subjective rating of a building's ability to attract tenants. The tiered rating is based on a number of factors, including rent, building finishes, system standards and efficiency, building amenities, location/accessibility and market perception.

Table 7: Building Class Definitions[15]

Class A (Tier "A")	Most prestigious buildings competing for premier office users with rents above average for the area. Buildings have high quality standard finishes, state of the art systems, exceptional accessibility and a definite market presence.
Class B (Tier "B")	Buildings competing for a wide range of users with rents in the average range for the area. Building finishes are fair to good for the area. Building finishes are fair to good for the area and systems are adequate, but the building does not compete with Class A at the same price.
Class C (Tier "C")	Buildings competing for tenants requiring functional space at rents below the average for the area.

[15] Source: BOMA International website. Accessed October 30, 2013. Available at http://www.boma.org/research/pages/building-class-definitions.aspx.

Building class has not generally been given consideration in previous energy benchmarking studies. For the purposes of this study, the class of a building was obtained from publicly available ratings on Altus InSite – a leading provider of national office market data for Canada's commercial real estate sector.

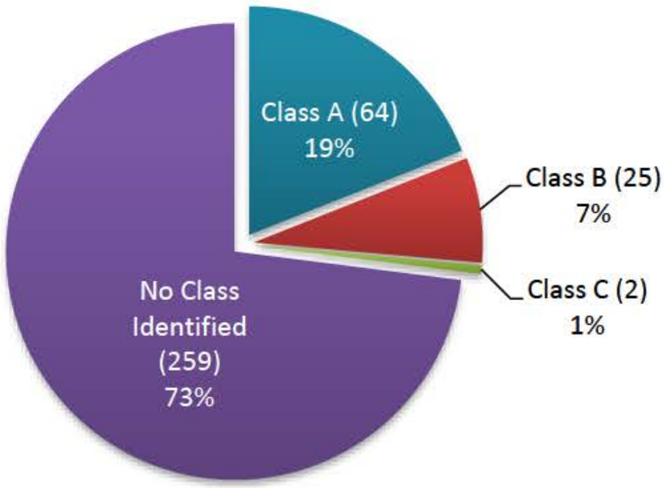


Figure 4: Sample Commercial Buildings by Building Class

3.4. Energy Sources

Findings revealed interesting trends in energy sources for different building types. Office buildings in the study consumed relatively more electricity than other fuel sources compared with NRCAN's national average. In contrast, MURBs were more reliant on natural gas, but still consumed less than the national average. These trends may due in some degree to the relatively low price of electricity in British Columbia.

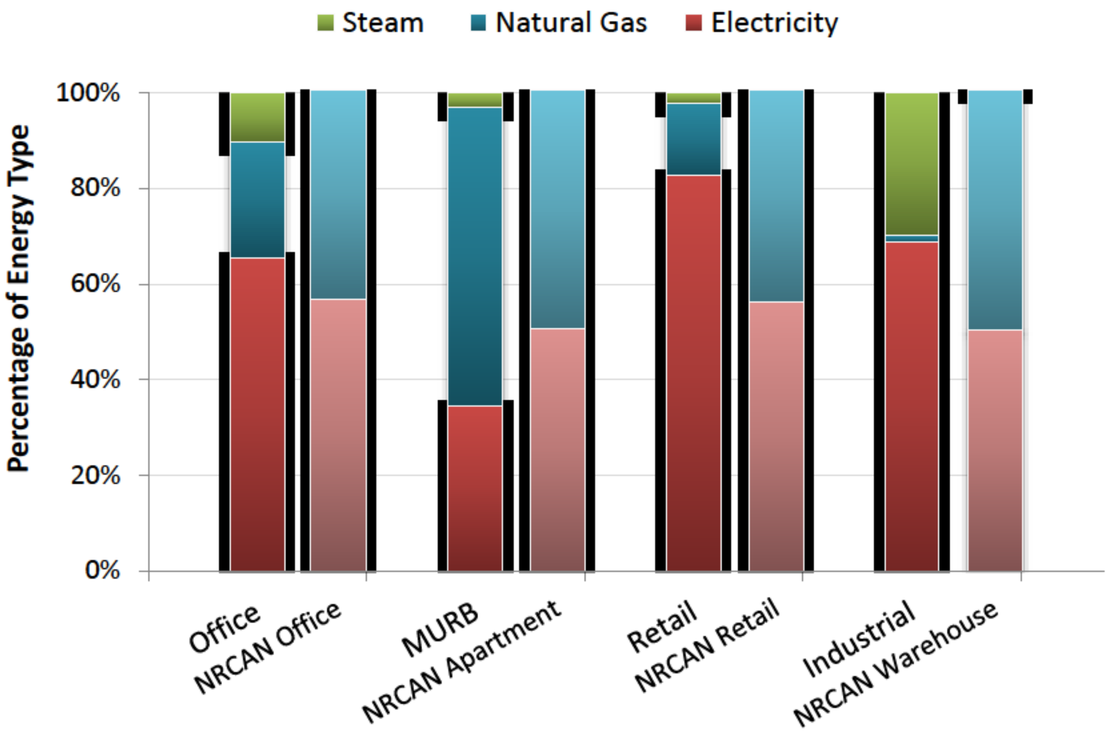


Figure 5: Distribution of Energy Sources by Building Type

Both BOMA BESt certified and non-certified offices and retail buildings used 10 to 20 percent more electricity on average than the NRCAN BC provincial average[16]. This is likely attributable to the fact that 89% of buildings in the study were located in the Lower Mainland climate zone A where average annual heating degree days are approximately 2,600 per year, compared to the rest of the Province, which has between 4,000 – 6,000 annual heating degree days.[17] The relatively low demand for heating energy amongst buildings in climate zone A likely accounts for the greater percentage of electricity consumed by these buildings relative to total building energy use.

3.5. Certification Level

Of the 147 BOMA BESt certified buildings in the study, the vast majority were level 2 and 3 certified office buildings. Table 8 shows the number of buildings by type and certification level in the study. Again, the relatively small number of certified buildings in other building categories made it difficult to draw general conclusions about building performance for those categories.

Table 8: Number of BOMA BESt certified buildings by level of certification

Certification Level	Level 2	Level 3	Level 4
Office	80	38	3
MURB	1	3	1
Retail	10	9	0
Other	1	1	0
Total	92	51	4

[16] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/query_system/querysystem.cfm?attr=0
[17] http://www.rdhbe.com/projects/index/projects/291.php

Twenty-two buildings indicated that they had undergone recertification of which 9 initially certified at level 2 or higher offering two points of data for comparison purposes (see section 4.1.6 of this report for consideration of recertified buildings). BOMA BESt level 1 certified buildings were excluded entirely from the study (see section 2 of the report for detailed discussion of the study's methodology).

4. HOW DO BC BUILDINGS PERFORM?

The primary objective of the study was to explore the state of building performance in British Columbia and the extent to which performance correlates with various building characteristics. This section benchmarks building performance of all buildings in the sample set grouped by building type and evaluates energy, waste and water performance based on floor area, age, class, energy source, and climatic zone (location) to provide a better picture of how BC buildings are performing overall.

4.1. Office Buildings

4.1.1. ENERGY PERFORMANCE

In the context of exploring the relationship between rating systems and building performance, the area of most interest at present related to energy performance. Energy performance sample set was analyzed with respect to building type, age and size. General energy performance trends were compared with those identified in New York City's 2013 building benchmarking report, one of the first jurisdictions in North America to mandate tracking of building energy performance and the first to publicly report out on overall performance trends.[18]

As detailed in section 2 ("Methodology"), buildings were excluded that reported energy performance that deviated significantly from the rest of the data set (i.e., buildings that reported a site EUI of less than 15.8 kWh/m^2/yr or more than 2,050 kWh/m^2/yr). This resulted in 10 buildings being removed from the data set sample.

The study data set included 175 office buildings (i.e., 52% of all buildings in the study), including 121 BOMA BESt certified and 54 non-certified office buildings. Weather normalized site EUI values for BOMA BESt Levels 2,3 and 4 certified office buildings and non-certified buildings were compared against NRCAN's EUI benchmarks for Canada (2009 and 2010 values) and BC and the Territories, as well as benchmark data from the BOMA BESt Energy and Environment Report (BOMA BEER) and the Real Property Association of Canada's building energy performance target of 215.8 ekWh/m^2/year by 2015.[19]

Figure 6 shows the distribution curve of energy intensity for both BOMA BESt certified and non-certified office buildings in the study. Site EUI varied considerably across both certified and non-certified office buildings, although not to the degree found amongst NYC buildings.

[18] New York City Local Law 84 Benchmarking Report (September 2013) available at http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/ll84_year_two_report.pdf. Comparisons with the NYC report were limited to trends. Average values were not compared because of the many differences in the two studies, notably climatic conditions.
[19] Ian Jarvis, *REALpac 20 by '15* (2009) available at http://c.ymcdn.com/sites/www.realpac.ca/resource/resmgr/industry_sustainability_-_research_reports/20-by-15final18sept09.pdf. See summary of benchmarks in Appendix A.

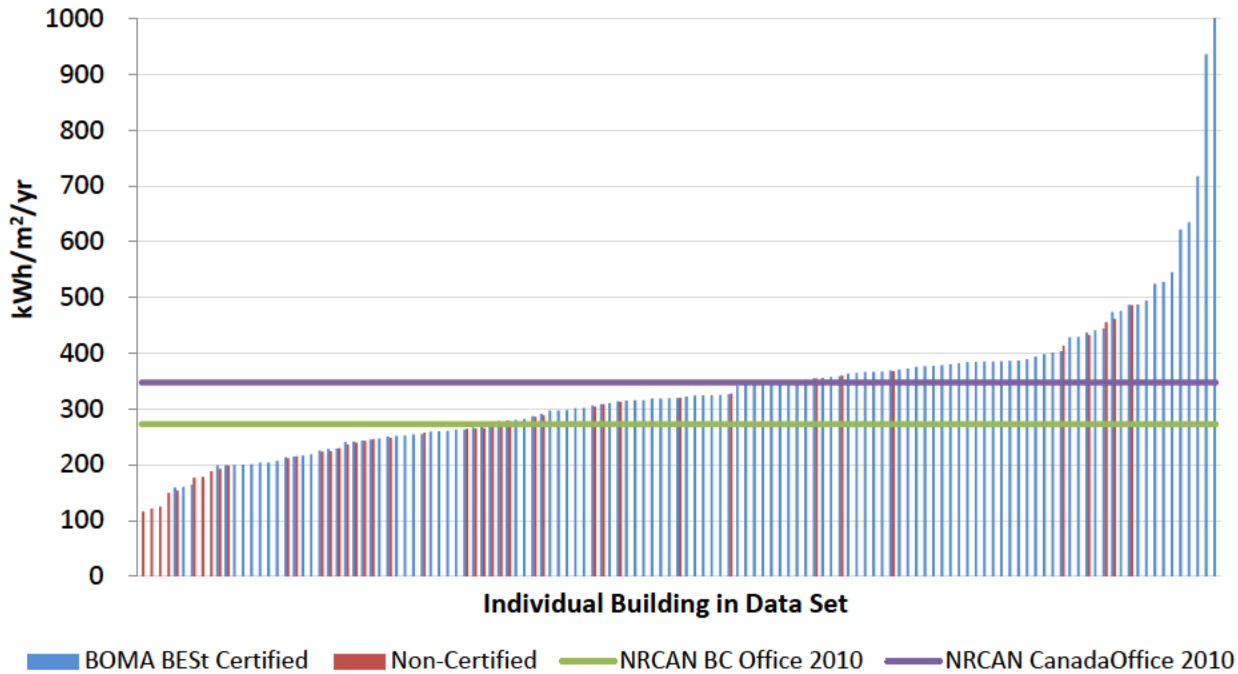


Figure 6: Energy Use Intensity of Office Buildings by Building

The sample of office buildings reveals a significant opportunity for energy savings amongst office buildings in British Columbia.[20] The average site EUI for all 175 office buildings was 319 kWh/m^2/yr. The top 25th percentile had an average EUI of 243 kWh/m^2/yr compared with 372 kWh/m^2/yr for the bottom quartile. In terms of total energy consumption, the top 25th percentile of office buildings consumed 14% of the total energy consumed, while the bottom 25th percentile consumed 34% (see Table 9). Extrapolating these findings, bringing the bottom quartile of office buildings up to the median EUI for all office buildings in the study would result in a potential reduction of 5% of total energy consumption by all office buildings in the Province.

Table 9: Top and Bottom Quartile Energy Consumption for Office Buildings

	Average kWh/m^2/yr	Total kWh	% of Total Energy Consumed
Top Quartile	243	98,807,700	14%
Bottom Quartile	372	236,594,600	34%
Median	306	368,498,500	

4.1.1.1. By Building Age

It is unclear whether the year a building was built has a material impact on its current energy performance. The NYC Benchmarking Report found that older buildings were on average outperforming their newer counterparts and attributed this to increased ventilation in newer

[20] The NYC Study found that bringing the lowest 25th percentile up to median levels would energy consumption by 18% and if they could bring those lowest 25th percent up to the top 25th percent they would reduce energy consumption by 31 percent.

buildings, better building envelopes in older buildings (less glazing) and higher energy intensity users in newer buildings.[21] However, while the findings from this study are inconclusive, the trend suggests that newer buildings in British Columbia are performing better on the whole than older ones.

For the 121 BOMA BESt certified office buildings, the study found a very slight correlation between the age of a building and energy performance (see Figure 7). The trend line suggests that on average the newer the building the better its energy performance. More specifically, the best performing buildings were built between 1980 and 1990, while the lowest performing buildings were built between 1960 and 1970. This last finding could possibly be attributed to the fact that the systems in the older buildings are nearing end of life and are in need of recommissioning, or possibly, replacement.

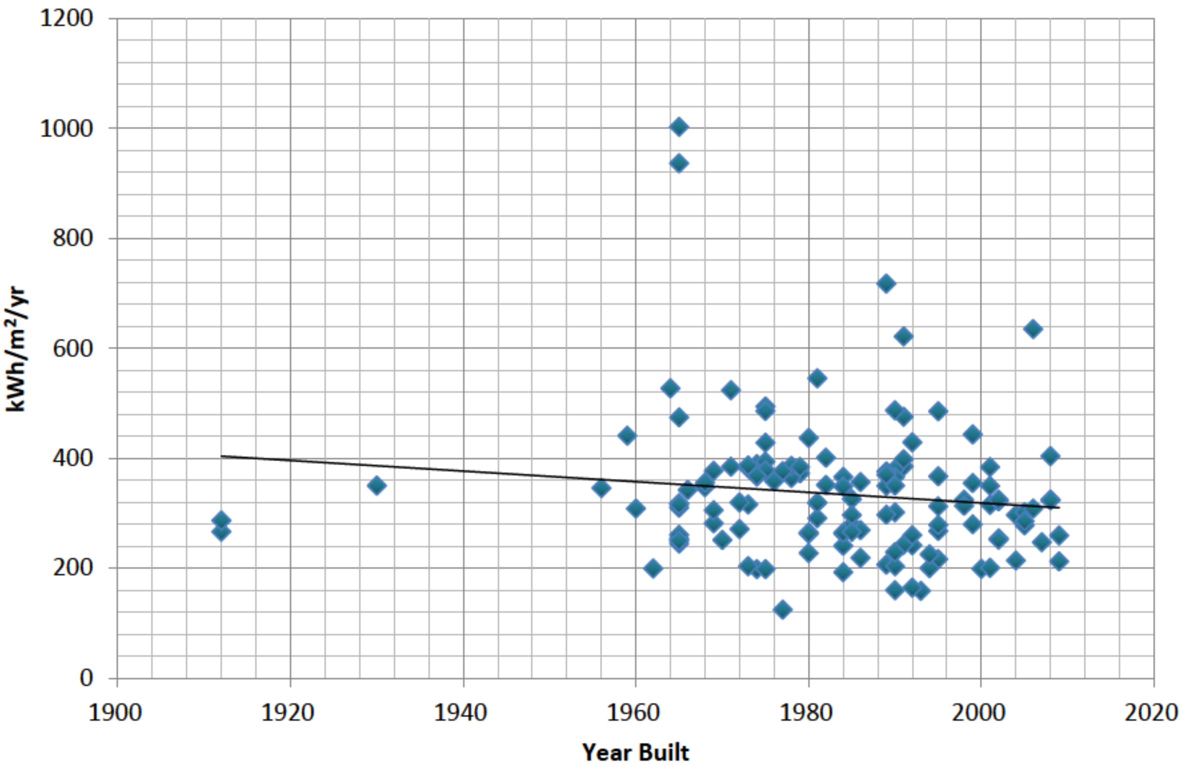


Figure 7: Average EUI for BOMA BESt Office Buildings by Building Age

4.1.1.2. Number of Floors

The data indicates a small correlation between increased energy usage and taller, high-rise office buildings (>26 floors) (see Figure 7).

[21] See footnote 18 above.

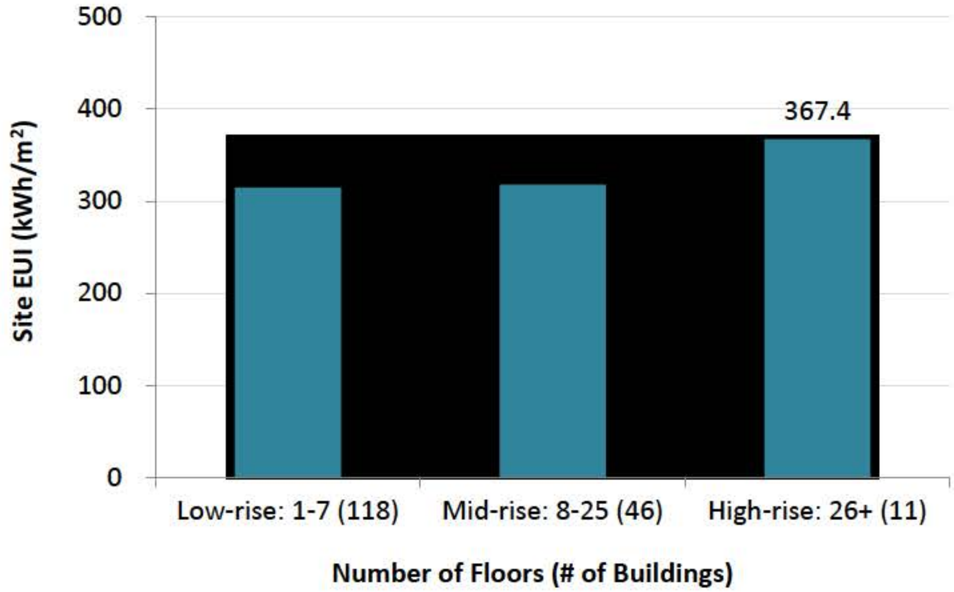


Figure 8: Energy Use Intensity of Office Buildings by Number of Floors

4.1.1.3. Floor Area

For the purpose of comparing energy use intensity and building size, all 175 certified and non-certified office buildings were assessed together because there were insufficient non-certified buildings on their own in each size category. The data shows a slight overall negative correlation between building size and EUI amongst office buildings.

Figure 9: Site EUI for Office by Floor Area

4.1.1.4. By Certification Level

While BOMA BESt does not prescribe minimum energy performance requirements, there is an expectation that buildings with a higher certification level will perform better than those with a lower level of certification. Indeed, BOMA BESt Level 4 certified office buildings performed 15% better than the NRCAN BC average, while Level 2 and Level 3 certified buildings performed 32% and 15% worse than the NRCAN BC average respectively. In contrast, Level 2, 3 and 4 BOMA BESt office buildings performed 4%,10% and 34% better respectively than the NRCAN Canada benchmark. Interestingly, non-certified office buildings performed almost identically to the NRCAN BC average and better than BOMA BESt Level 2 and 3 certified office buildings. The average performance of the non-certified office buildings was virtually the same as NRCAN's BC average lends a degree of confidence to the findings (see **Figure 21**).

4.1.1.5. Building Class

One of the criticisms levelled against historical studies looking at the energy performance of commercial buildings is that they have included a disproportionate number of higher performing Class "A" buildings providing a skewed picture of overall building performance. Indeed, the same observation has been made with respect to the performance of certified buildings relative to non-certified buildings generally. This study included 64 Class A buildings, 25 Class B buildings and 2 Class C buildings. Results indicate that Class A buildings outperformed Class B and C buildings with respect to energy performance, however the number of Class C buildings considered was not large enough to make valid comparisons.

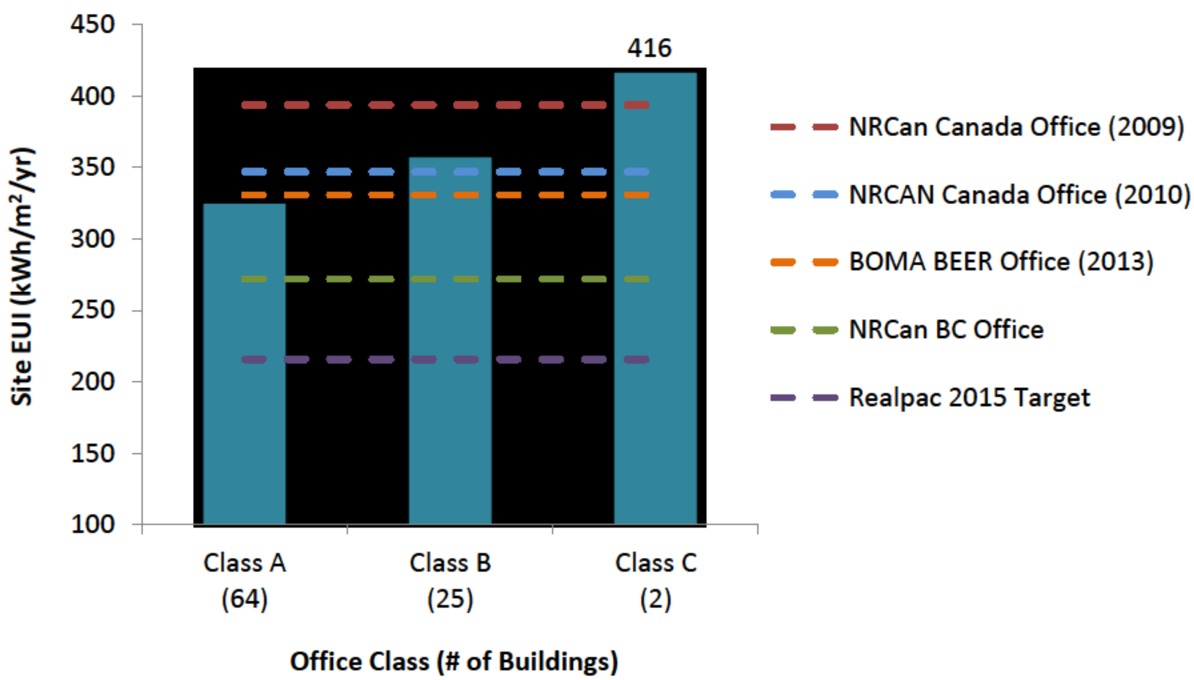


Figure 10: Average EUI of Office Buildings by Building Class

4.1.1.6. Climatic Zone

British Columbia has three climate zones. The geographic location of a building impacts a building's design and operation in a myriad of ways, including design standards, the availability and use of materials, and even the availability of qualified individuals to operate and maintain the building. The vast majority of the buildings in the study were located in climate zone A, performing better than the NRCan and BOMA Canada averages, but underperforming with respect to NRCan's benchmark for BC and the Territories. Unfortunately, the insufficient number of buildings in climate zones B and C did not allow for a comparison of building performance across different climate zones.[22]

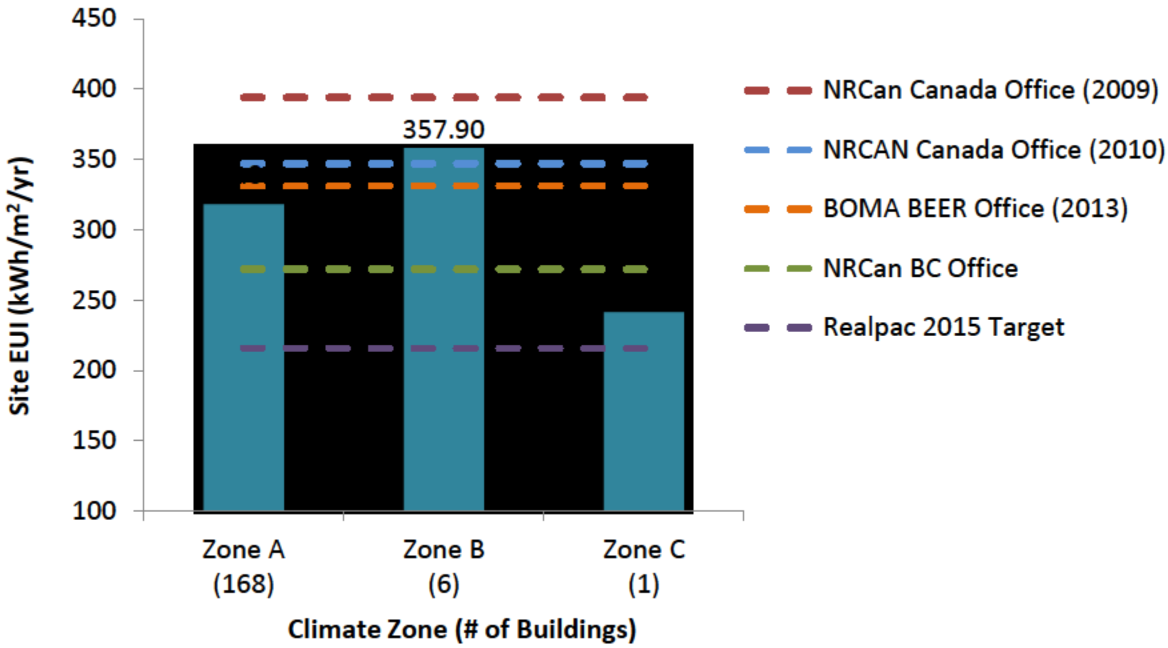


Figure 11: Average EUI for Office Buildings by Climatic Zone

4.1.1.7. ENERGY STAR Score

ENERGY STAR is an American-based rating system for products and buildings. Buildings that use Portfolio Manager® to track their energy performance can also obtain an ENERGY STAR rating by benchmarking their performance relative to other buildings across Canada. ENERGY STAR scores are expressed on a scale of 1 to 100. Buildings must obtain a score of 75 or greater to get an ENERGY STAR rating, which indicates that the building is in the top quartile of its class.

Portfolio Manager® was introduced in Canada in July 2013. Currently, only two classes of buildings are eligible to obtain an ENERGY STAR rating in Canada (i.e. offices and K-12 schools). Consequently, only 175 of the 331 buildings in the study would be eligible at this time. Figure 12 shows a distribution curve of the average ENERGY STAR scores for qualifying buildings. Of those, 27 office buildings (15%) obtained a score higher than 75 points.

[22] The one office building in Zone C was a BOMA BESt Level 2 building.

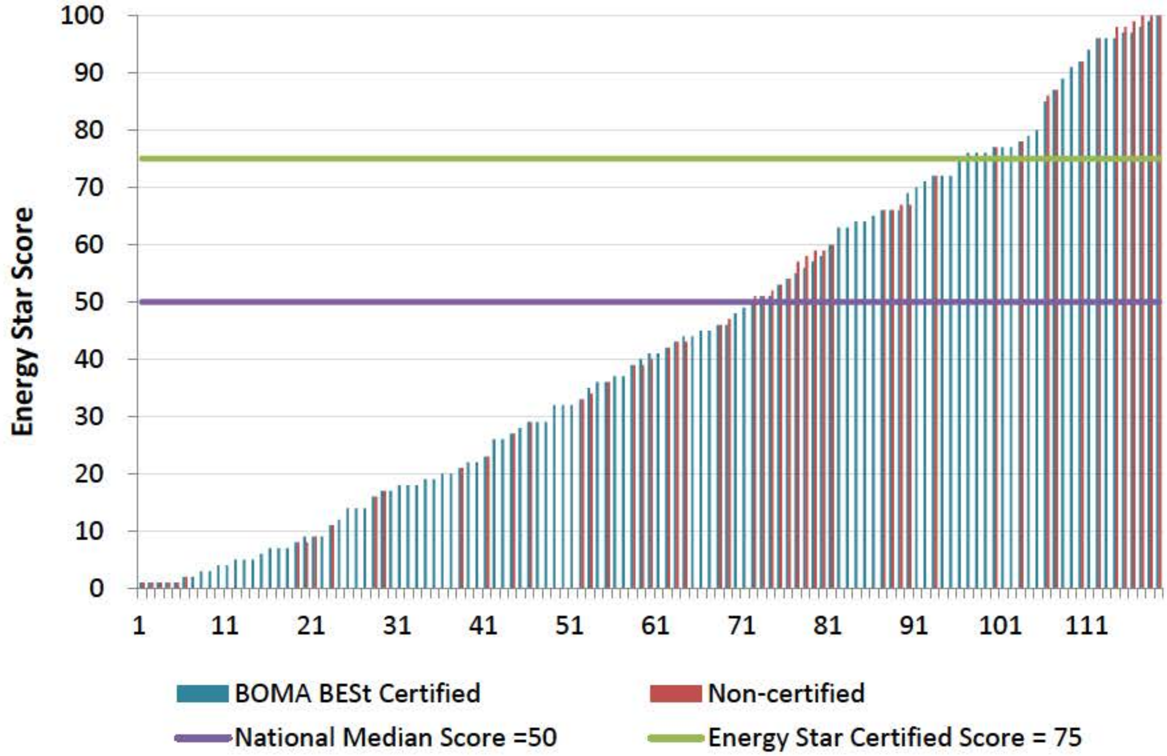


Figure 12: ENERGY STAR Scores Distribution for Office Buildings

4.1.2. GHG Emissions

With the current focus of governments on meeting greenhouse gas reduction targets, findings regarding GHG emissions from office buildings present some interesting results. GHG emission factors were calculated using Portfolio Manager® using its methodology for calculating and tracking greenhouse gas emissions.[23] However, benchmarking building performance is not meaningful in this context because fuel sources and associated emissions vary depending on location.

As with energy performance, newer office buildings showed a slight reduction in GHG emissions, although the findings are not statistically significant (Figure 13).

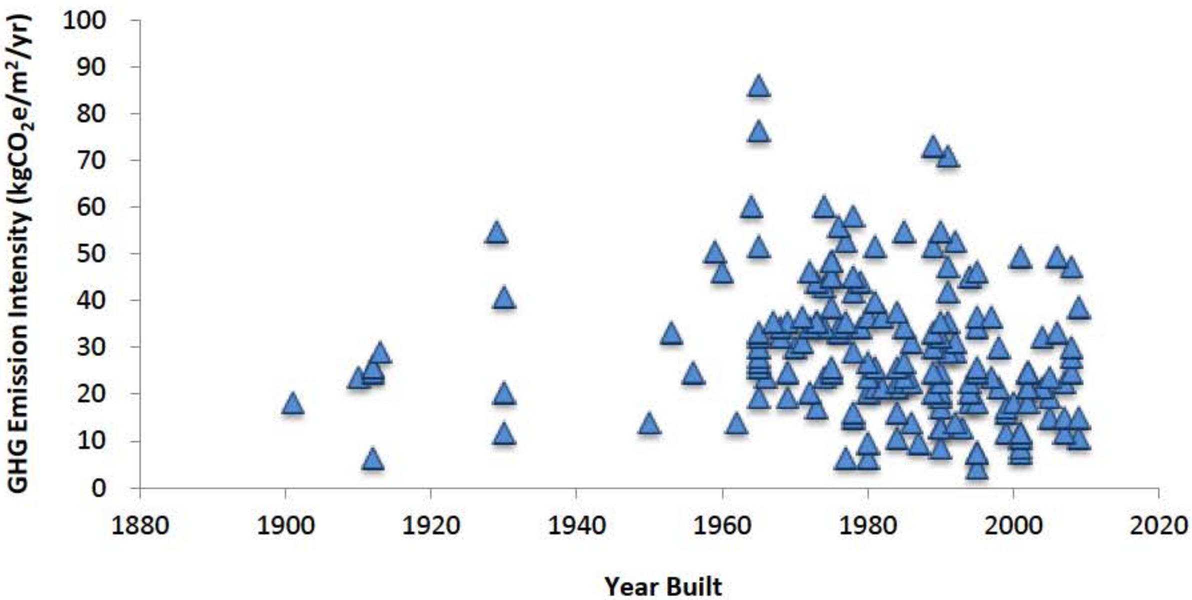


Figure 13: GHG Emissions for Office Buildings by Building Age

The study's findings do show a positive relationship between the number of floors in a building and its GHG emissions. Figure 14 shows that high-rise buildings (i.e., buildings with more than 26 floors) emit roughly 25% more GHG per square metre than low-rise buildings.[24] Interestingly, this trend observed with respect to GHG emissions is not observed when looking at energy consumption (see Figure 8 above).

[23] *See* www.energystar.gov/ia/business/evaluate_performance/Emissions_Supporting_Doc.pdf.
[24] Building height classifications come from BOMA.

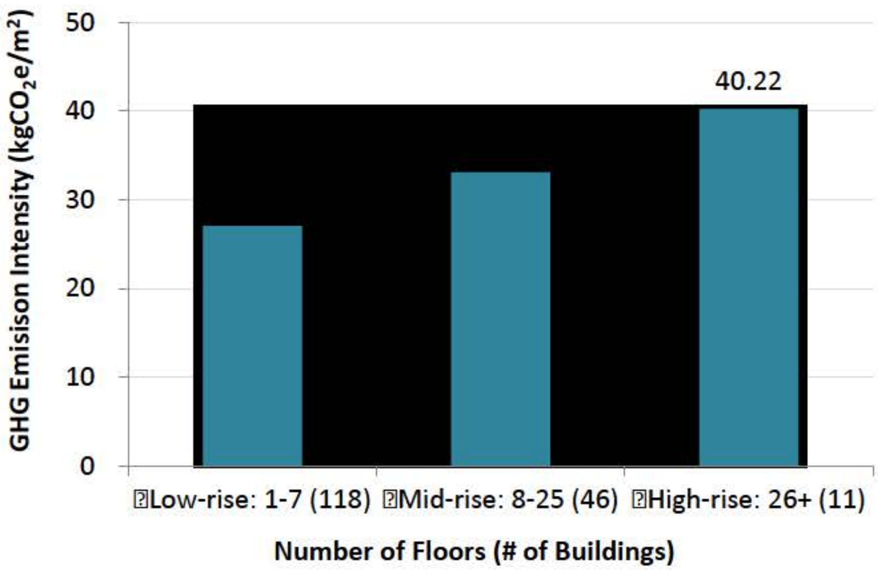


Figure 14: GHG Emission Intensity of Office Buildings by Number of Floors

There are several possible explanations for this. The higher average GHG emission intensity amongst mid-rise buildings is likely due to higher relative gas usage. Low-rise buildings tend to use relatively more electricity, which in British Columbia comes from hydroelectric sources with significantly lower emissions. High-rise buildings are also more likely to have a greater percentage of glazing and curtain walls filled with windows, which decrease their energy efficiency and increase their emissions.

However, the relationship is not sustained when looking at office buildings by square footage. In that case, no clear trend is observed (see Figure 15). Both very small buildings (<25,000 ft^2) and large office buildings (250,000 – 500,000 ft^2) showed the highest levels of GHG emission intensities.

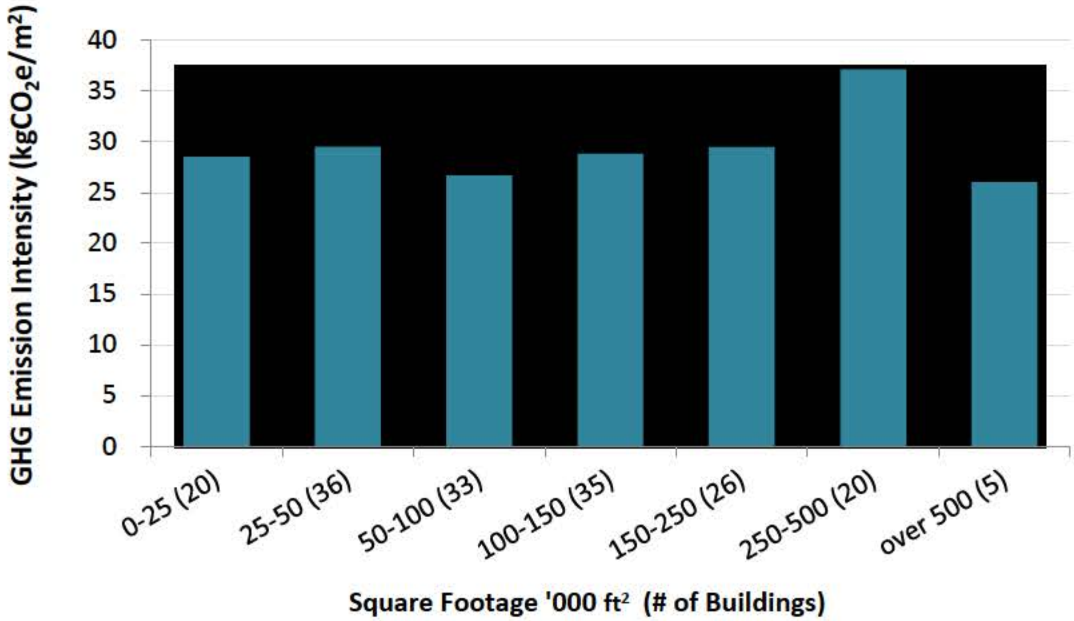


Figure 15: GHG Emission Intensity for Office Buildings by Square Footage

While the data is not conclusive, findings suggest that high-rise buildings represent the greatest potential for GHG emission reductions per building amongst office buildings. However, given the larger number of low-rise and mid-rise buildings in British Columbia, policy targeting those buildings might achieve greater overall reductions in GHG emissions.

4.1.3. Water Usage

British Columbia has one of the highest water consumption rates (based on bulk water consumption) of any province in Canada.[25] This is largely due to extremely low water rates and lack of metering which makes it very difficult to charge for domestic water consumption. The residential sector in BC accounts for 65% of the province's total water consumption, while the commercial sector accounts for 16% (see Figure 16). Metro Vancouver's distribution is similar with the residential sector accounting for 60% of the region's water consumption and the remaining 40% used by business and industry.[26] The City of Vancouver's building sector accounts for approximately 12% of total potable water consumption for the municipality.

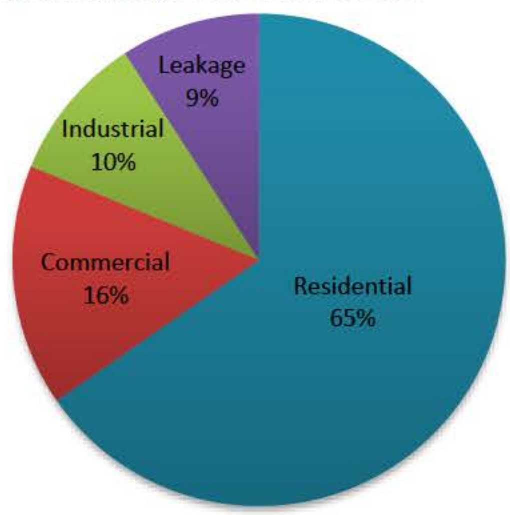


Figure 16: Water Consumption in BC by Sector

[25] Environment Canada, *2011 Municipal Water Use Report* available at http://www.ec.gc.ca/Publications/B77CE4D0-80D4-4FEB-AFFA-0201BE6FB37B/2011-Municipal-Water-Use-Report-2009-Stats_Eng.pdf. The survey (based on 2009 data) shows that municipalities with volume based water charges have an average residential consumption rate of 229 litres per capital per day (Lcd) compared with municipalities without metering or volume based pricing with 376 Lcd; an increase of 65%.

[26] Metro Vancouver, source?

There have been several benchmarking studies on office building water consumption in Canada. REALpac's *Water Management: A Benchmark for Canadian Office Buildings* issued in May 2011 analyzed water usage for 74 buildings using 2009 water usage data.[27] The study found the best practice range for office buildings across Canada, representing first quartile performers, was 128 to 535 L/m^2/yr. Best performing (i.e., top quartile) buildings in BC and the prairies consumed less than 407 L/m^2/yr. Similarly, the median consumption for buildings in BC and the prairies was 642 L/m^2/yr, significantly less than the 984 L/m^2/yr for Ontario buildings. BOMA Canada's 2011 Energy and Environmental Report on BOMA BESt buildings (the majority of which were office buildings) found national average water consumption intensity for BOMA BESt certified buildings was 600 L/m^2/yr,[28]

For the purposes of this study, water consumption data was limited to 115 BOMA BESt certified buildings in BC. Non-certified buildings were asked to provide this information through an online survey, but were either unable or unwilling to provide it. Three buildings were excluded based on reporting significantly higher consumption levels than the rest of the data set. Despite this, the results still showed a wide range of water use intensity values across buildings, similar to findings in the REALpac water benchmarking study.[29] The average water use intensity for the study's office buildings was 1,032 L/m^2, significantly higher than both comparative benchmarks. More than 60% of the buildings had higher water use intensity values than the average value reported by REALpac and the bottom quartile of buildings had values exceeding 190 L/m^2.

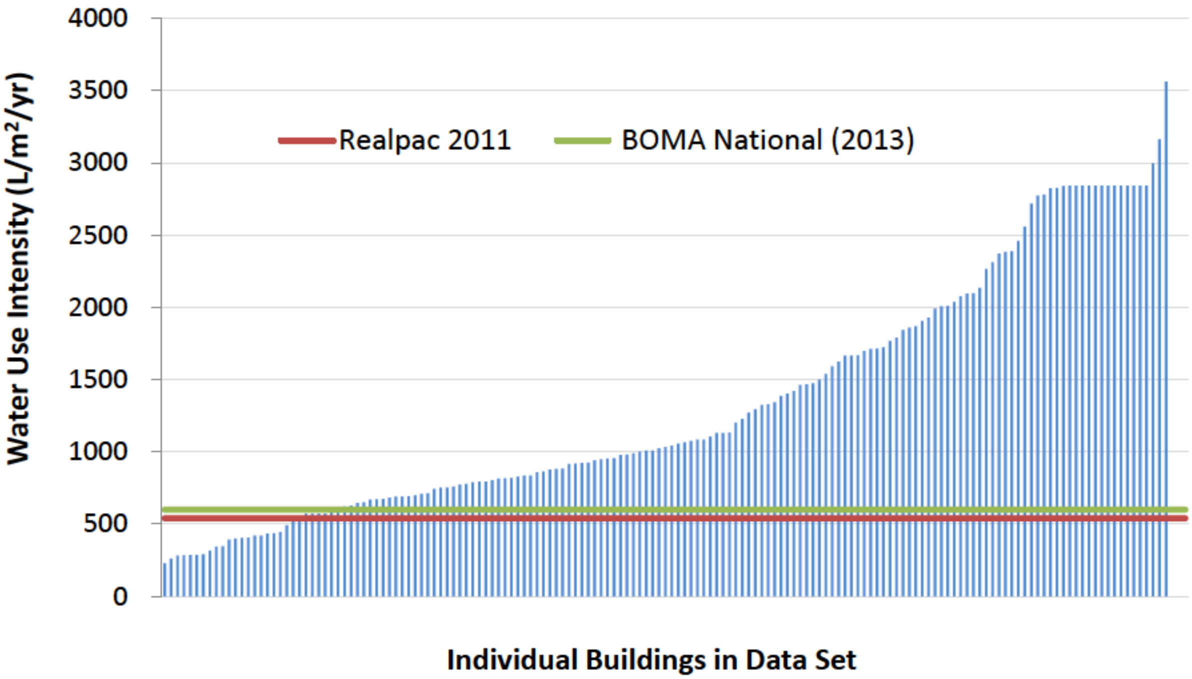


Figure 17: Water Use Intensity Distribution for Office Buildings

The findings indicate that there is considerable opportunity to improve water efficiency and reduce consumption among BC buildings. This includes commissioning existing infrastructure and

[27] REALpac, *Water Management: A Benchmark for Canadian Office Buildings* (May 2011) at p.18. Available at http://c.ymcdn.com/sites/www.realpac.ca/resource/resmgr/industry_sustainability_-_water_benchmarking/rp-water-management-and-benc.pdf.

[28] BOMA Canada, *BOMA BESt Energy and Environment Report 2013*. Available at http://www.bomabest.com/wp-content/uploads/BBEER-2013-Full-Report.pdf.

[29] REALpac, *supra* note 27.

addressing occupant behaviour. Further segmentation of water use intensity data is recommended to better identify the bottom quartile of buildings and focus the design of water conservation policy and programs.

Water delivery and treatment also requires significant energy and can result in considerable emissions. Actual indirect energy requirements for water delivery and wastewater treatment can vary considerably depending on a jurisdiction's infrastructure, as well as each building's location and total water consumption. Other studies have reported significant indirect energy use intensity levels from water delivery and wastewater treatment, not including water heating.[30] These indirect values are not commonly incorporated into energy consumption values for buildings and have not been included for the purposes of this study, however their impacts warrant further study.

4.1.4. Waste

Waste diversion considers the amount of non-hazardous materials that are diverted from going to landfill through recycling or reuse. Office buildings generally report diversion rates based on receipts provided by the waste disposal company that services the building.

There are no recent benchmarking studies on waste diversion in Canada, however the 2013 BOMA BEER found that 45% of BOMA BESt certified buildings diverted between 30% and 60% of their waste from landfill.[31] A number of jurisdictions have set overall waste diversion targets, such as Metro Vancouver's objective of diverting 70% of all wastes from landfill by 2020.

BOMA BESt only requires buildings to report diversion rates in percentage increments of ten. Furthermore, BOMA BESt assigns a default diversion rate of 10% to buildings that do not report waste diversion values. These buildings are represented in Figure 18, but were excluded for the purposes of calculating the sample's median and mean. Assuming all buildings reporting 10% diversion rates did not provide waste data, this represents a significant opportunity to engage property owners and managers in reporting waste data.

Of the 121 BOMA BESt certified office buildings in this study that reported waste diversion data, the average diversion rate was 59% and the median was 55%, reflecting the upper range for BOMA BESt certified buildings nationally as reported in the 2013 BOMA BEER.

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[30] See e.g., Carol Mass. 2009. *Greenhouse Gas and Energy Co-Benefits of Water Conservation.* Polis Project. Table 1 at pg. 9. Available at http://poliswaterproject.org/sites/default/files/maas_ghg_.pdf.
[31] BOMA Canada. 2013. BOMA BESt Energy and Environment Report. Page 42. Available at http://www.bomabest.com/wp-content/uploads/BBEER-2013-Full-Report.pdf

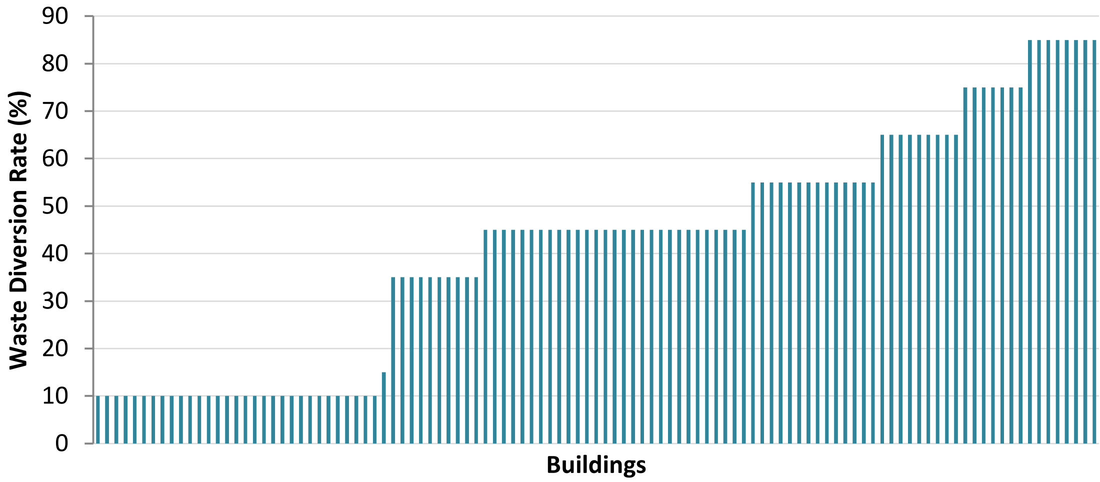

Figure 18: Waste Diversion Distribution for Office Buildings

4.1.5. ENVIRONMENTAL MANAGEMENT ACTIVITIES

The BOMA BESt program creates an incentive for building operators to focus on environmental management activities such as conducting energy, water, and waste audits, creating targets and reduction goals and surveying occupants on comfort and their ideas to increase building performance and reduce environmental impacts. Up to 11% of total points are available under the BOMA BESt rating system for environmental management best practices. Unlike data obtained on resource consumption, the information on environmental management activities was pulled from BOMA BESt audits conducted on 169 BOMA BESt buildings. The results indicated that while some building owners, managers and operators were taking advantage of these points, it is an area where there is room for improvement (see Figure 19).

Specifically, the results indicated that managers and operators of BOMA BESt certified buildings are diligently creating energy management policies (99.3%), which include tracking annual energy use, creating reduction targets and working towards continual improvement. BOMA BESt certified buildings are often using green leases with tenants (76.9%), which include a section on energy and environmental responsibilities. The results indicated that 75.7% of building owner / operators were also conducting staff training on energy and building management systems. Further, 81.1% stated that they had an environmental policy manual, which included sections dealing with energy conservation and GHG emissions reduction, water conservation, waste reduction and recycling, environmental purchasing, and proper handling and the reduction in use of hazardous products. Finally, just over half (55%) of the 169 buildings reported conducting waste audits every three years. These results indicate that BOMA BESt is a useful tool in driving improvements at the policy and program level for many buildings.

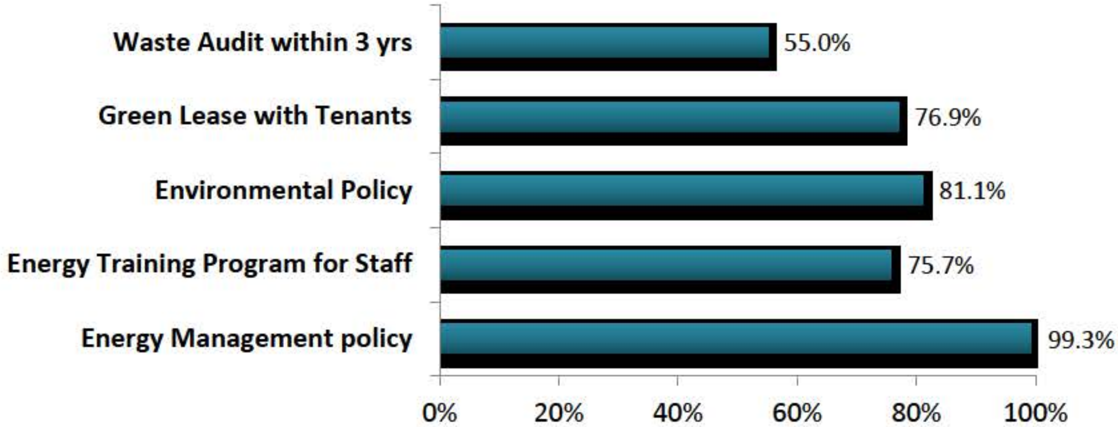

Figure 19: Management Activities of BOMA BESt Certified Buildings

4.1.6. RECERTIFICATION

The majority of buildings in British Columbia were built in the 1960s and 1970s and most of their systems are nearing the end of life. This highlights the need for ongoing monitoring and maintenance of existing buildings to ensure that building systems are operating as efficiently as possible. The combination of benchmarking, auditing and retro-commissioning is recognized as an essential part of building management and the most effective means of reducing costs and improving a building's performance.

As mentioned previously, both BOMA BESt and LEED EB:O&M recognize the importance of ongoing building assessment and require buildings to recertify every 3 years in order to maintain their rating status. However, the two rating systems have different approaches to engaging buildings. LEED EB:O&M sets performance requirements that buildings must meet to attain certification. BOMA BESt does not set minimum performance requirements, but rather encourages all building owners and operators to start to benchmark where they are at in terms of building environmental performance and then work on continual improvement. The BOMA BESt program is therefore more inclusive of all buildings and not solely seeking the top performers. It is through the process of recertifying that improvements in building performance can be identified.

Of the 147 BOMA BESt buildings in the study, 22 were identified as having recertified, 7 of these were identified by referencing BOMA BESt report cards and another 15 were manually identified by matching building addresses and names (see Figure 20). Since the data was analyzed a further 139 BOMA BESt buildings and 28 additional recertified buildings were discovered in a third BOMA database, however no energy data was available for these buildings and they could not be included in the result. Performance improvements could only be evaluated on buildings that provided original and recertified energy data. Consequently, only 9 buildings were ultimately considered. These nine buildings were all office buildings larger than 75,000 ft^2, with the exception of one retail shopping centre. All were built after 1977.

Recertification Path	Total # of Buildings
Level 1 to 2	9
Level 1 to 3	4
Level 2 to 2	2
Level 2 to 3	4
Level 3 to 3	2
Level 3 to 4	1

Figure 20: Recertification Pathway for BOMA BESt Buildings

As **Figure 21** illustrates, BOMA BESt certified office buildings that had only certified once reported an average site EUI of 367.88 kWh/m^2/yr; poorer than any individual level of certified buildings. In contrast, buildings that had recertified experienced a 25% improvement in energy performance with an average site EUI of 280.70 kWh/m^2/yr, in line with the NRCAN BC benchmark. With the exception of one building (that certified and recertified Level 2), all buildings reported at least a 20% reduction in EUI (see Figure 22).[32]

[32] Some of these buildings recertified under the more stringent BOMA BESt v.2, however for the purposes of energy performance, both versions of BOMA BESt are identical.

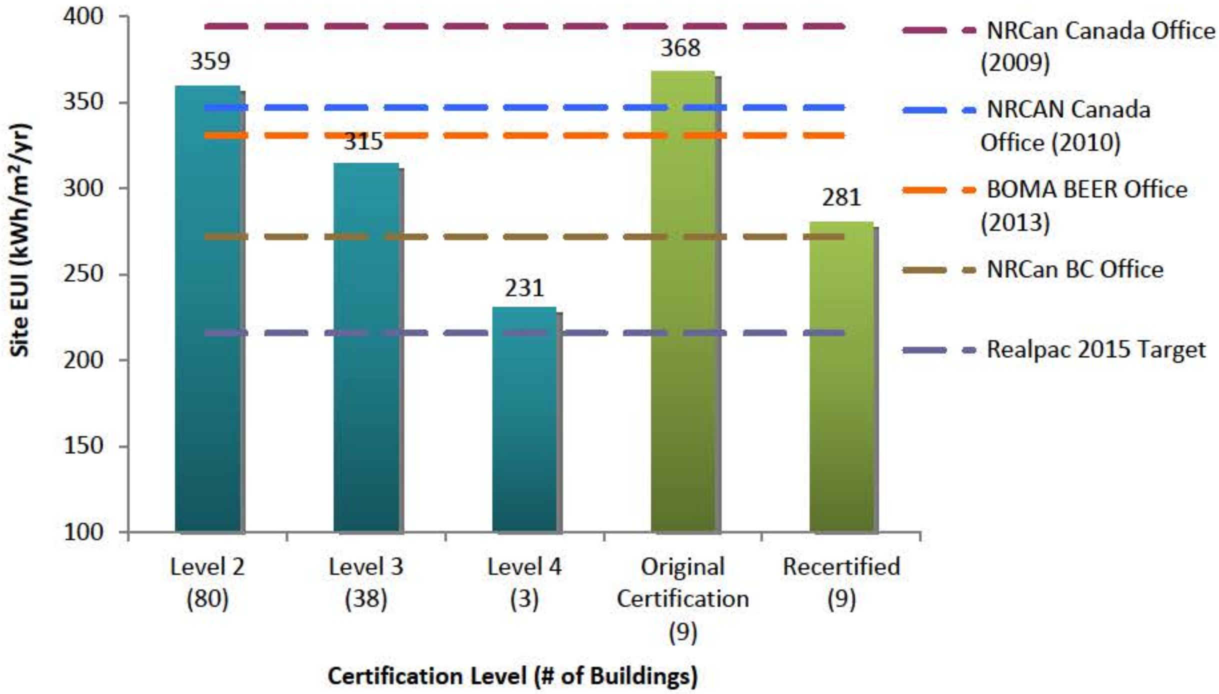

Figure 21: Average Site EUI for BOMA BESt Certified and Recertified Office Buildings

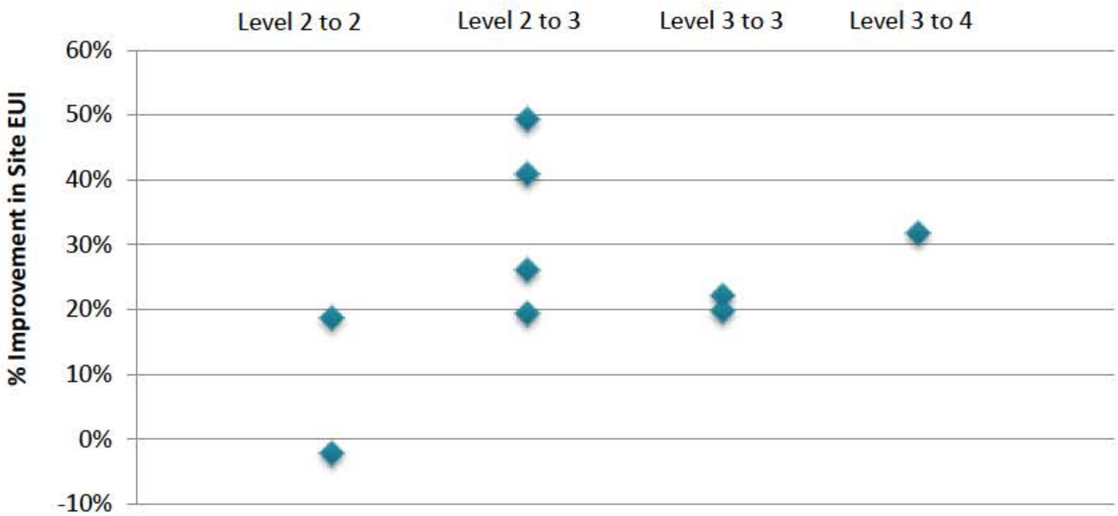

Figure 22: Percentage Improvement in EUI Among BOMA BESt Buildings That Recertified

The eight recertified buildings that reported water consumption data during their original certification and at the time of recertifying achieved an average 30% reduction in annual building water usage per square meter (see Figure 23: Percentage improvement in Water Use Intensity for BOMA BESt Buildings That Recertified).

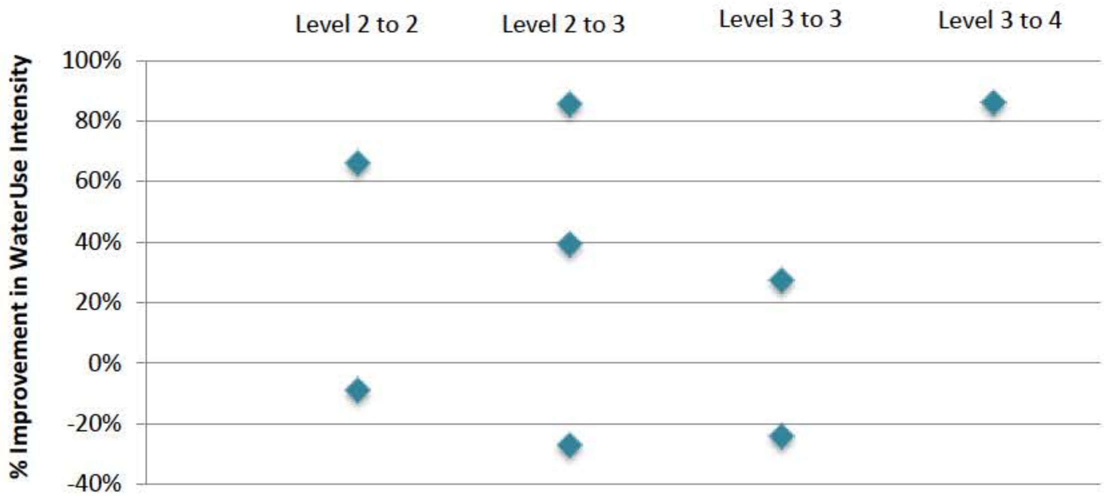

Figure 23: Percentage improvement in Water Use Intensity for BOMA BESt Buildings That Recertified

With respect to waste diversion, all 22 BOMA BESt buildings that recertified provided waste diversion rates at the time they certified originally and when they recertified, thus providing a stronger sample set. The 22 buildings reported an average increase of 24% in their diversion rates, going from an average diversion rate of 43.7% during their original certification to 67% upon recertification. However, those buildings that originally certified at Level 2 or higher achieved a more modest average increase of 8% (see Figure 24).

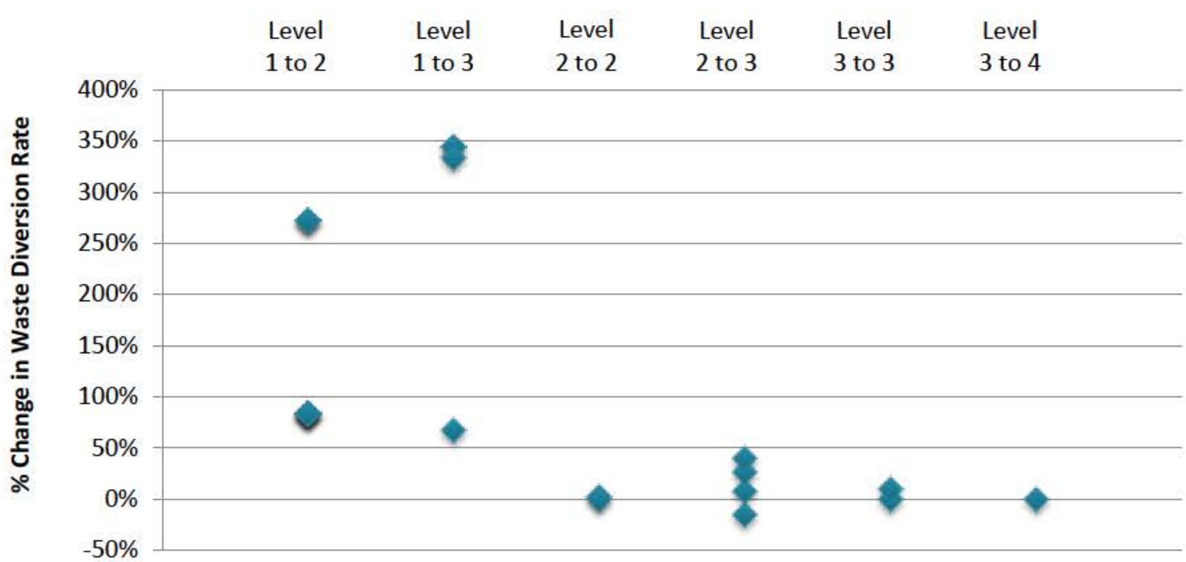

Figure 24: Percentage Change in Waste Diversion Rates for BOMA BESt Buildings That Recertified

Despite the relatively small sample set, the results suggest that the recertification process offers an effective tool for stimulating performance improvements in buildings, including reductions in EUI and water usage and increased waste diversion rates. The results also indicate that BOMA BESt attracts all types of buildings and performers and is a useful tool not just for high performing buildings but is being used by many lower performing buildings as a means to start benchmarking environmental performance and work towards continual environmental improvement.

4.2. Multi-Unit Residential Buildings

The study included 115 multi-unit residential buildings comprising 41% of the total data set, including 110 non-certified and 5 BOMA BESt certified buildings[33]. As with office buildings, ten buildings representing the top and bottom 2% of all MURBs were excluded from the study. The small number of BOMA BESt certified buildings is, in part, a consequence of BOMA BESt only introducing a rating framework for MURBs in 2012. There were no MURBs in the study group that recertified.

4.2.1. Energy Performance

Findings were compared with three different benchmarks for residential buildings, including the NRCAN BC 2005 benchmark for low-rise MURBs and benchmarks from two research studies looking at 41 MURBs in Metro Vancouver (FRESCo)[34] and 39 MURBS from Vancouver and Victoria (RDH)[35]. As discussed in the methodology section the benchmark studies did not use a weather normalized approach to benchmarking. However the authors of this study feel strongly that weather normalized benchmarking will become more common for benchmarking studies in the future with the introduction of Portfolio Manager® in Canada.

The distribution curve for multi-unit residential buildings was similar to that observed for office buildings with significant variances in performance (see Figure 25).

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[33] Certified buildings broke down further into one Level 2 certified building, three Level 3 certified buildings and one Level 4 certified building.

[34] FRESCo. (February 2013). *Energy Labelling in Multi-Unit Residential Buildings* (February 2013). The study surveyed the performance of 41 multi-unit residential facilities comprised of 52 buildings in Metro Vancouver with a total floor area of approximately 4.7 million square feet. Source EUI values of the 41 facilities ranged from 226 to 741 kWh/m^2/yr, with an average of 434 kWh/m^2/yr.

[35] RDH Building Engineering. (2012). *Energy Consumption and Conservation in Mid and High Rise Residential Buildings in British Columbia.* The RDH study determined an average site EUI of 213 kWh/m^2/yr for 39 multi-unit residential buildings in Vancouver and Victoria.

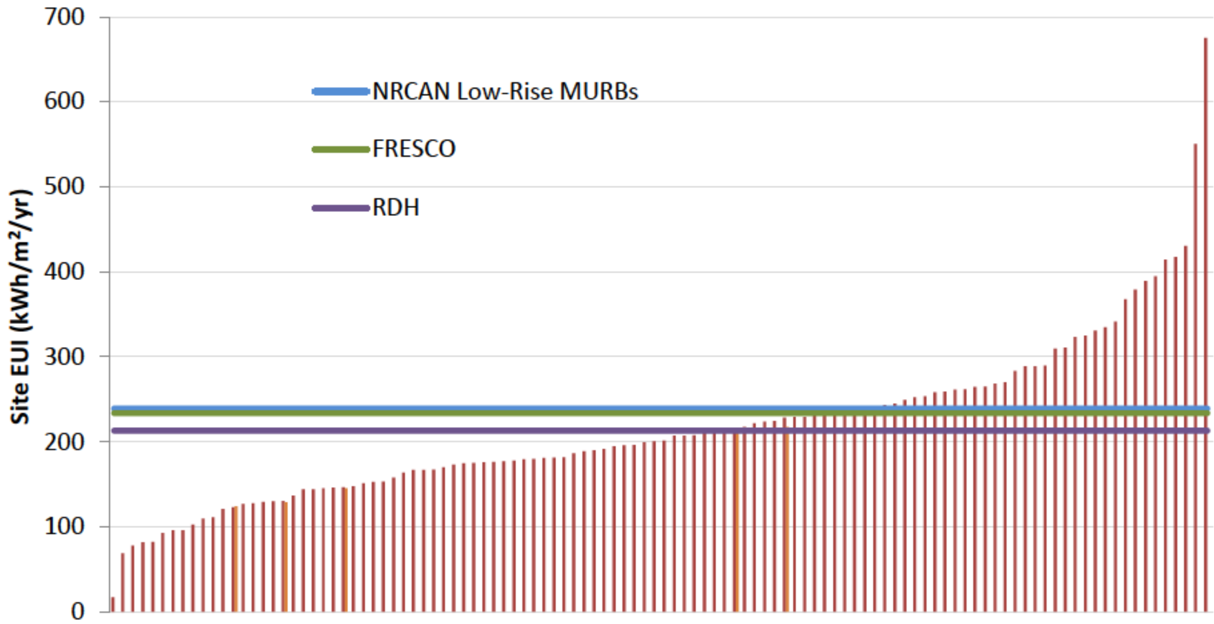


Figure 25: Distribution Curve of Site EUI for Multi-Unit Residential Buildings

The average site EUI for all MURBs was 215 kWh/m^2/yr with the top quartile achieving an average site EUI of 153 kWh/m^2/yr and the bottom quartile averaging 259 kWh/m^2/yr (see Table 10). In terms of total energy consumption the top quartile consumed 13% of the total energy consumed by all MURBs in the data set, whereas the bottom quartile used 30% -- two and a half times as much energy as the top 25th percentile. As with office buildings, the study's findings indicate that bringing the bottom 25th percentile of MURBs up to the median EUI would result in a 5% reduction in total energy consumption for all MURBs.

	Average kWh/m^2/yr	Total kWh/yr	% of Total Energy Consumed
Top Quartile	153	22,669,013	13%
Bottom Quartile	259	51,198,703	30%
MURB Median	201	172,626,559	

Table 10: Top and Bottom Quartile Average Site EUI for Multi-Unit Residential Buildings

4.2.1.1. By Building Age

Findings for MURBs were similarly inconclusive when considering site EUI and the age of the building. For all 115 MURBs in the study, a slight trend was observed between building age and energy performance suggesting that the newer the building the better its energy performance, although it is important to stress that the findings were not statistically significant (see Figure 26).

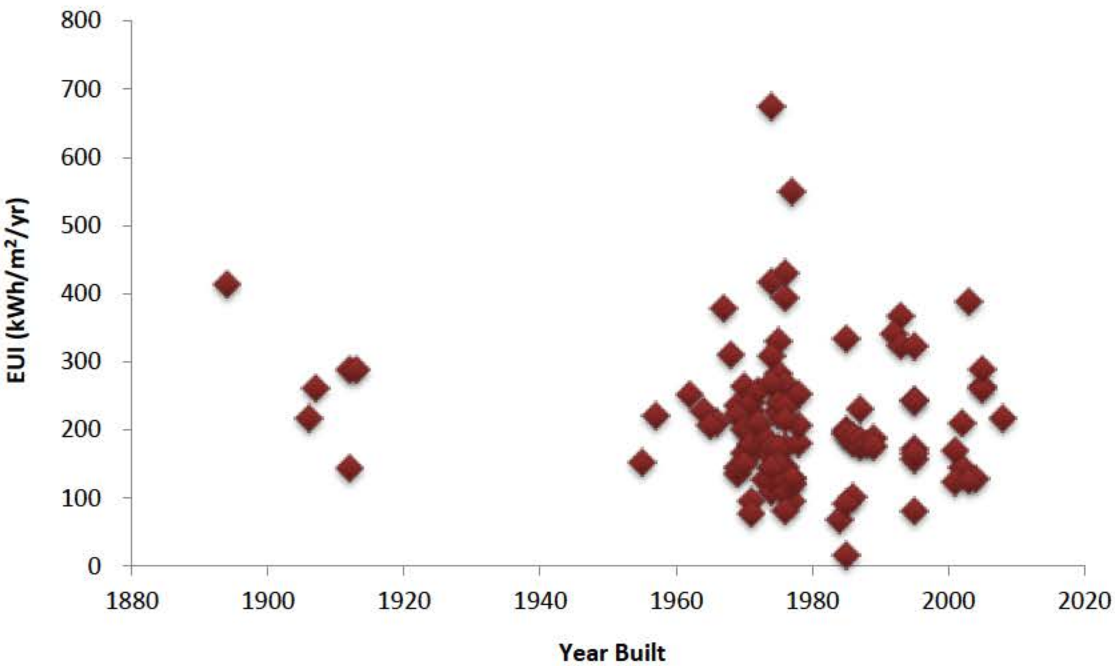


Figure 26: Energy Use Intensity v. Building Age for All MURBs

4.2.1.2. By Number of Floors

Unlike office buildings, the data showed no correlation between energy use intensity and the number of floors in MURBs (see **Figure 9** and **Figure 18**).

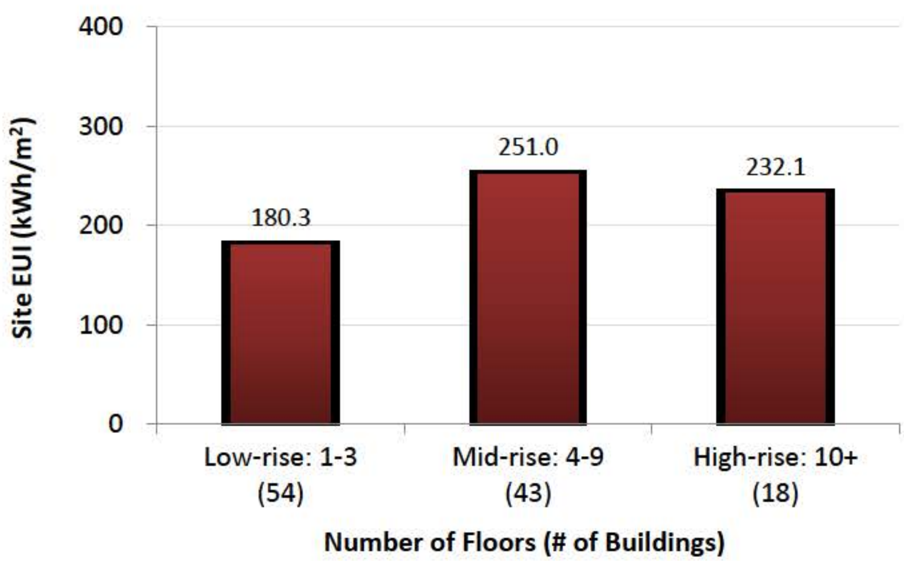


Figure 27: Average Energy Use Intensity of MURBs by Number of Floors

According to the MURBs in the study's sample, low-rise MURBs performed 28% better than mid-rise MURBs and 22% better than high-rise MURBs. The performance of low-rise MURBs is again likely due to their predominantly wood construction compared to their taller counterparts that feature concrete structures with thermal bridging and higher percentages of glazing. More surprising is the fact that GHG emission intensities for large buildings were 8% better than for mid-rises. This could be because 37 (86%) of the mid-rises were built before 1990 and 56% of the high rises were built after 1990. The mid-rises are therefore slightly older and the high-rises slightly newer.

4.2.1.3. By Floor Area

MURBs showed a similar distribution to office buildings when considered by size. Referencing the findings based on the number of floors, the results confirm that the size of a building is not related to the number of floors.

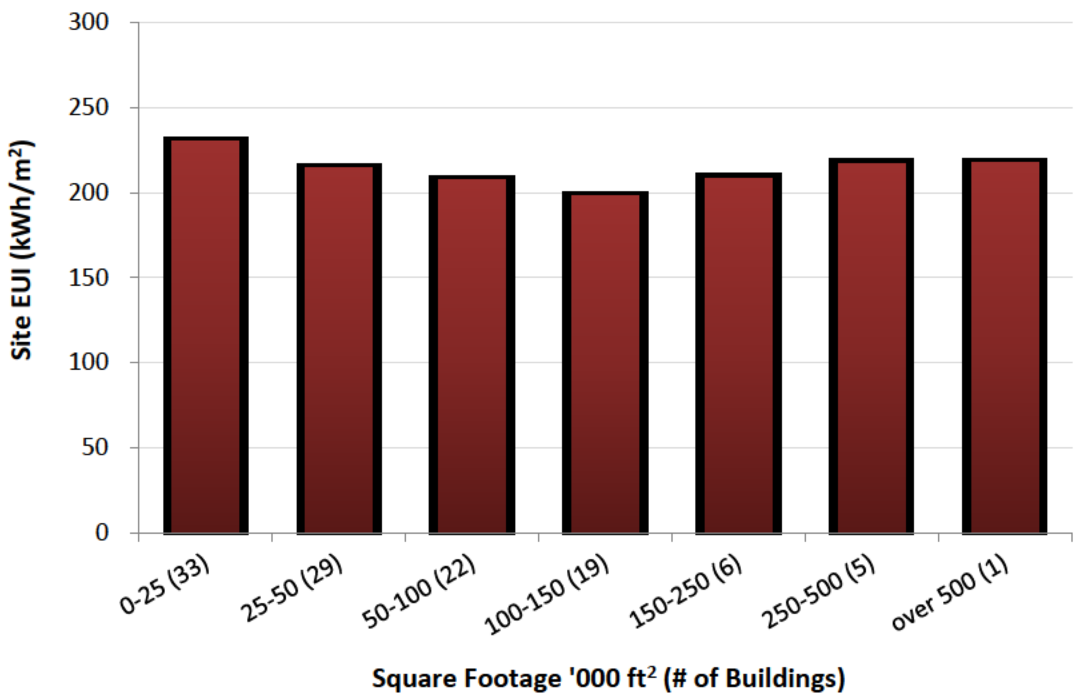
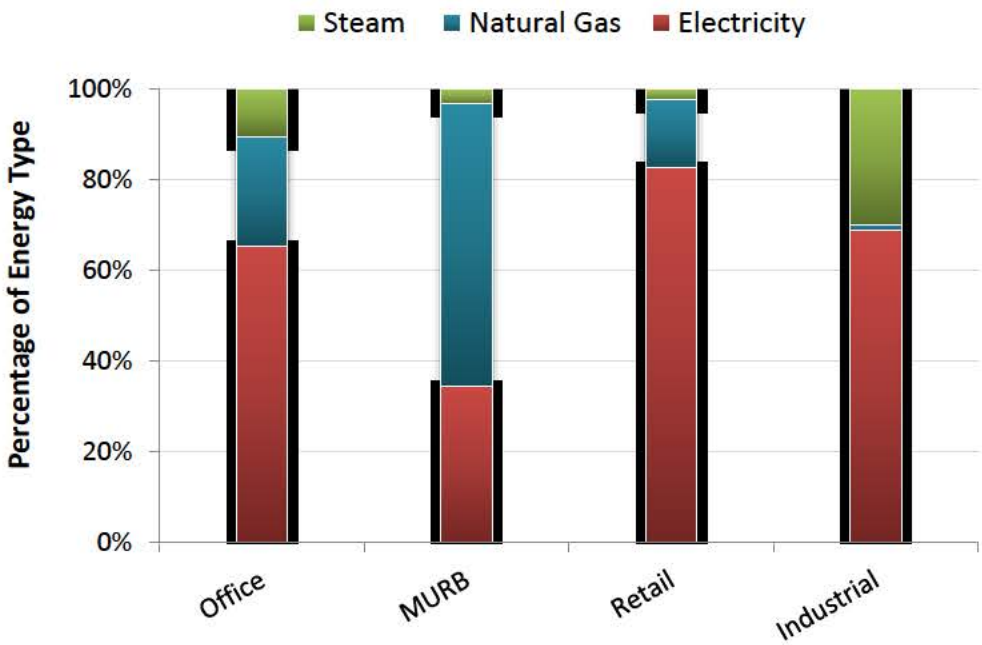


Figure 28: Average Site EUI for MURBs by Floor Area

4.2.2. GHG Emissions

GHG emission intensity values for MURBs mirrored energy use intensities whether segmented by building age, number of floors and total square footage (see **Figure 29**, **Figure 30**, and **Figure 31**).

The rationale for the variations in average GHG emission intensity values is presumably similar to that described in relation to energy use intensity values above. In addition, the fact that low-rise MURBs use proportionately higher percentages of electricity generated from hydroelectric power contributes to their lower average value (see **Figure 5**).



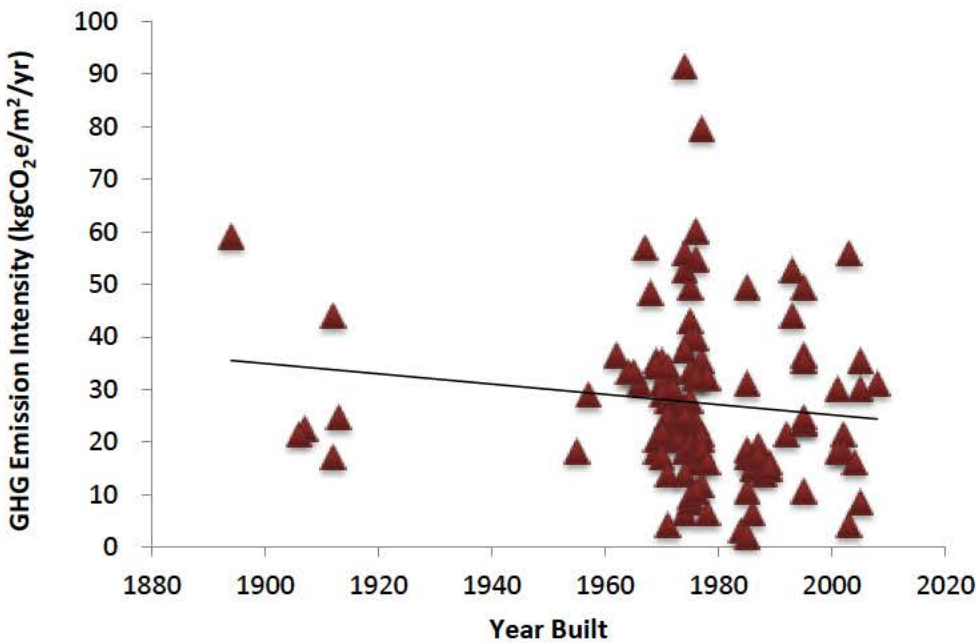


Figure 29: GHG Emission Intensity of MURBs by Building Age

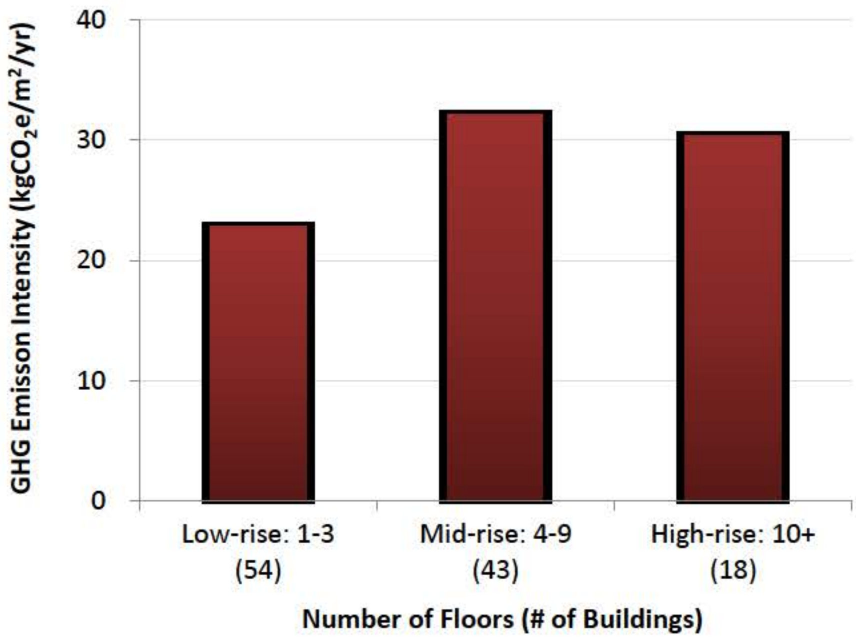


Figure 30: Average GHG Emission Intensity of MURBs by Number of Floors

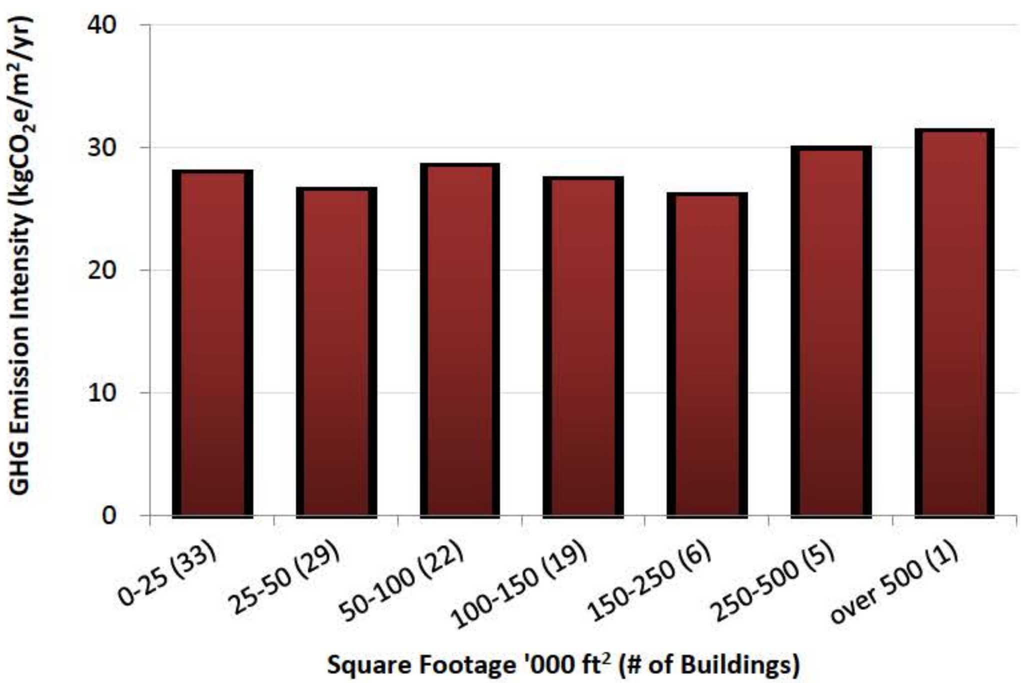


Figure 31: Average GHG Emissions for MURBs by Floor Area

5. THIRD-PARTY RATING SYSTEMS AND GREEN BUILDING POLICY

This section explores the second and third questions posed at the outset of this study, namely, can third-party certification systems for existing buildings help governments in BC to meet their green building and related policy objectives? And if so, what else can / should governments in BC do to require / encourage / incentivize the pursuit of third-party certification systems for existing buildings?

5.1. BC's Policy Framework

The Province of British Columbia, as well as regional and local governments within the Province, have established a number of targets aimed at addressing climate change and resource consumption issues. As indicated in the introduction to this study, achieving these targets is heavily dependent on the contribution of buildings. Many question whether the Province's existing policy framework is adequate to achieve these legislated targets.[36] Table 11 references the existing legislation and regulation in British Columbia and their key objectives. With the exception of the City of Vancouver, the Province has jurisdiction over setting performance requirements for buildings. Despite their limited ability to influence policy with respect to buildings, regional and local governments are active in the implementation of Provincial policy, including the adoption of provincial requirements into local policy and permitting requirements and the development of educational tools. Accordingly, this section references Provincial policy targets recognizing that regional and local targets are similar.

Table 11: Provincial Policy Instruments and Key Policy Objectives

Category	Policy Documents	Key Objectives
Energy & GHGs	BC Greenhouse Gas Reductions Act (2007)	▪ Reduce GHG emissions by 33% by 2020 from 2007 levels ▪ Reduce GHG emissions by 80% by 2050 from 2007 levels
	Local Government Statutes Act	▪ Local and regional governments must identify greenhouse gas emission reduction targets as part of Official Community Plans and Regional Growth Strategies with supporting policies, plans and actions to achieve those stated targets.
	BC Energy Efficient Buildings Strategy	▪ Reduce average energy demand per home by 20% by 2020 ▪ Reduce the energy demand at work by 9% per sq. metre by 2020. Make government buildings carbon neutral by 2010.
	BC Energy Efficiency Act	▪ Specifies efficiency performance for appliances and products (including windows, furnaces, fluorescent ballasts).

[36] Dirk Meissner, "Greenhouse Gas Emissions in B.C. Meet Targets, For Now" (September 25, 2013). *Huffpost British Columbia*. Available at http://www.huffingtonpost.ca/2013/09/25/bc-greenhouse-gas-emissions_n_3991140.html; Ellen Post, "British Columbia needs local government innovation to meet its climate targets" (Pembina Institute, September 13, 2013). Available at http://www.pembina.org/blog/749.

Category	Policy Documents	Key Objectives
	BC Building Code	▪ Commercial, institutional and larger residential buildings must meet the ASHRAE 90.1 (2004) standard. (AHSRAE 90.1 (2010) as of December 31, 2010).
Water	BC Living Water Smart Water Act Modernization Project	▪ Reduce water use by 33% by 2020 ▪ 50% of municipal water requirements to be met through conservation by 2020
Waste	The Environmental Management Act (previously Waste Management Act)	▪ Require all Regional Districts prepare and submit solid waste management plans setting out regional waste targets.

	Metro Vancouver Integrated Solid Waste and Resource Management Plan (2010)	▪ Reduce quantity of waste generated per capita within the region to 90% or less of 2010 volumes by 2020
		▪ Increase diversion rate to 70% by 2015 and 80% by 2020. The 70% diversion is divided by sector:
		  ▪ Multi Family 30%
		  ▪ Single Family 65%
		  ▪ ICI 70%
		  ▪ Demo and Construction 80%

Local Planning	***Official Community Plans (OCPs)***	Sets the long-term vision for a community through overarching policies and objectives that apply to land use and development within a defined community area. The OCP can be a powerful decision making tool for municipalities around climate change, energy and water efficiency initiatives as well as waste reduction. Local government may adopt language within their OCPs that set targets with respect to sustainability in the built environment.
	Development Permit Area (DPAs)	Pursuant to the Local Government Act, local municipalities have expanded authority to address climate change through energy and water conservation and reduction of green house gas emissions. DPAs apply to elements that are **exterior** to single`` family, multi-family residential, commercial and industrial developments.
	Local Improvement Area Charges (LICs)	(LIC) provides a financial mechanism to recoup the costs associated with providing capital improvements within a defined area, a site or building. The costs are typically recovered using property taxes to owners that benefit from the improvements being made in the area.

5.2. Rating Systems for Existing Buildings

Third party rating systems have emerged through the private an non-profit sectors as an effective tool to rank or classify the comparative performance of buildings, thereby providing owners/operators with an incentive to improve existing building performance around key criteria such as energy, water and waste. A number of third party rating systems have been initiated in Canada focused specifically on the performance of existing buildings, most notably BOMA BESt and LEED for Existing Buildings (LEED EB:O&M). This section describes each rating system's approach and the implications on building performance improvement.

BOMA BESt is an industry-led third party environmental standard for building operations and maintenance, designed to help building owners and managers benchmark and manage improvements in building performance and environmental management. The rating system offers four levels of certification for a range of building types, including office, shopping centre, light industrial and open air retail, as well as a new module for multi-unit residential buildings (MURBs)[37]. Buildings seeking Level 1 certification must have established a series of 14 existing processes with respect to energy, water, waste, emissions, site, indoor environment and environmental management, but does not require reporting on specific performance measures. Levels 2 through 4 require buildings to provide performance data and all levels of BOMA are third-party verified. This voluntary certification system has seen considerable growth since its initial launch in 2005 with 1,668 buildings certified as of October 2013 and more than 2,900 having participated through certification and recertification since the program's inception.

BOMA BESt takes an inclusive approach, encouraging the participation of all buildings in performance improvement using a points-based system. As such, BOMA BESt does not set minimum performance thresholds, but rather awards a higher number of points for higher levels of performance. A building's environmental performance is based on six key areas of environmental performance and management including:

- Energy
- Water
- Waste Diversion
- Site Enhancement
- Emissions and Effluents
- Indoor Environment
- Environmental Management Systems

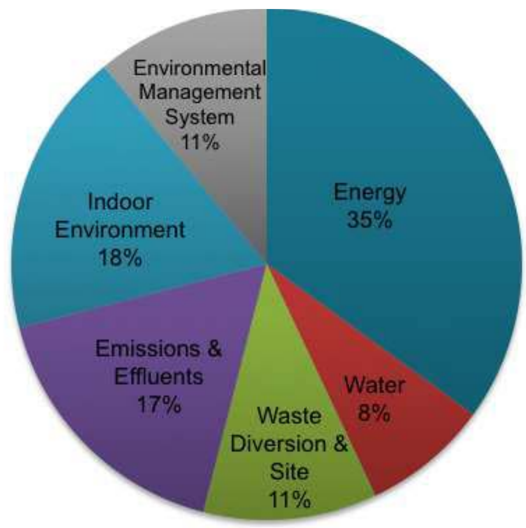


Figure 32: BOMA BESt Credit Breakdown for Office Buildings

BOMA BESt awards points for performance and for meeting certain criteria such as having high efficient lighting or LED exit signs and low-NOx boilers. The framework scores buildings out of 1,000 based on their performance in the six key areas (see **Figure 32** for a breakdown of points under BOMA BESt). A Level 2 BOMA BESt building must score between 70 – 79% on the BOMA BESt survey, a Level 3 building between 80 – 89% and a Level 4 building must achieve a score of 90% or higher. The energy section for Office Buildings in BOMA BESt is worth 35% of total points, with 8% of this directly related to how a building performs. Specifically, buildings can score up to 8% (80 points) for having a low energy usage intensity (i.e., less than 10 ekWh/ ft^2/yr). **Figure 33** provides a chart showing the allocation of points associated with a building's energy performance.

[37] Since MURBs have just recently been included in the certification process there are only 6 residential buildings in the data set; most of which were constructed after 2000.

ENERGY PERFORMANCE BENCHMARK SCALE

Office

Energy Use Intensity	Points
≤ 36 kWh/ft^2/yr	8
≤ 32 kWh/ft^2/yr	16
≤ 28 kWh/ft^2/yr	24
≤ 24 kWh/ft^2/yr	32
≤ 20 kWh/ft^2/yr	40
≤ 18 kWh/ft^2/yr	48
≤ 16 kWh/ft^2/yr	56
≤ 14 kWh/ft^2/yr	64
≤ 12 kWh/ft^2/yr	72
≤ 10 kWh/ft^2/yr	80

"≤" = Less than

Figure 33: BOMA BESt Points for Energy Use Intensity for Office Buildings

Key to the BOMA BESt framework is that certification only remains valid for three years. To foster an orientation towards continual improvement in building performance, buildings are required to recertify after three years and are encouraged to achieve higher levels of performance and certification in the process.

LEED for Existing Buildings Operation and Maintenance (LEED EB:O&M) is similar in its basic structure, offering four levels of certification using a point-based system that covers six aspects of building performance. However, LEED EB:O&M is fundamentally different in that it takes an exclusive approach, rewarding leaders in environmental performance by setting minimum performance requirements in six areas at each level of certification. As such, first-time certification implies that a building is performing at a certain level with respect to energy, waste and water consumption.

5.3. Credit Level Comparison of BOMA BESt and LEED EB:O&M

The findings with respect to BOMA BESt buildings suggest that the process of recertification under that regime can facilitate significant improvements in the building performance of existing buildings. Questions remain, however, as to whether these observations can be extended to other rating systems, specifically LEED EB:O&M, and the degree to which both rating systems align with British Columbia's policy objectives and by extension, those of regional and local governments.

LEED EB:O&M was introduced in Canada in 2009. Thus far, only 7 buildings have certified under that framework in British Columbia; too small a sample to provide any meaningful observations. In the absence of empirical data, the study attempted to extrapolate findings beyond BOMA BESt certified buildings by evaluating the comparability of the two rating systems. The assumption being that if the frameworks are similar then they should yield similar results in terms of building performance.

In attempting to evaluate the equivalency of the two rating systems, a credit-level comparison was conducted for the sections of each rating systems dealing with energy, waste and water. The relative distribution of points for each credit was considered along with the performance requirements for achieving those points and the average uptake of specific points amongst certified projects. The results were limited to some degree by the variance and degree of completeness of the reporting across the two systems. Based on information available, the study assessed whether there was a low, medium or high level of correlation between specific credits in both rating systems.

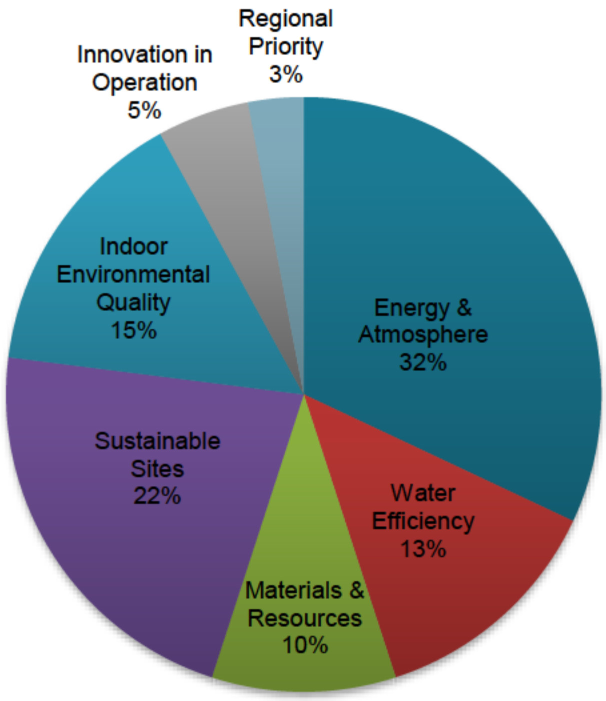


Figure 34: LEED EB:O&M Credit Breakdown

Both frameworks assign approximately the same relative percentages to the three key performance areas. As noted earlier, BOMA BESt awards a maximum of 1,000 points distributed across six areas; 56% covering energy, waste and water (see **Figure 32** above). Points for LEED EB:O&M are distributed in six categories with a maximum of 110 points; 55% covering energy, waste and water (see Figure 34). However, as noted previously, LEED sets minimum performance thresholds, whereas BOMA BESt awards points for difference levels of performance.

Sections pertaining to energy, GHG emissions, water and waste were compared to assess the degree of alignment between the basic credit requirements. Quantifying the potential overall impact of the various credits in terms of energy, GHG emissions, water and waste reduction was beyond the scope of this study. The study also identified the popularity of various credits to gain an understanding of the potential uptake in the voluntary context.

Generally speaking, BOMA BESt and LEED EB:O&M are not comparable. BOMA BESt is highly prescriptive with some focus on performance-based measures. In contrast, LEED EB:O&M is highly performance-based. It is relatively difficult to measure outcomes of prescriptive measures because buildings are a complex combination of interacting systems making it difficult to isolate the performance impacts of specific prescribed measures. By definition, performance based approaches are easier to measure in terms of outcomes. In short, with the exception of certain specific credits, while both rating systems recognize many of the same aspects of building performance, their different approaches make them difficult to compare with each other in relation to broader policy objectives. A detailed series of charts summarizing the credit-by-credit analysis undertaken are provided in Appendix C. Additional study is required to evaluate the net quantitative impact of specific credits in order to better assess their alignment with policy objectives. Unfortunately, this exercise was beyond the scope of this study. Regardless, it is clear that given the discretion in point and credit selection in the respective systems, it would be necessary to mandate fulfillment of specific points/credits to ensure that the use of either rating system meets environmental targets. Despite data on credit preferences amongst certified buildings, the ability of users to cherry-pick credits makes it impossible to assess with any certainty whether certification will support achievement of broader environmental policy objectives.

The ability to compare rating systems exists at the credit-level with respect to specific practices, if at all. Accordingly, the remainder of this section looks at the comparability of the key performance areas at a credit level under both rating systems.

5.3.1. Energy and GHG Emissions

With respect to energy and GHG emissions, BOMA BESt and LEED EB:O&M show a high degree of comparability in coverage, including environmental management systems, energy auditing, use of renewable energies, and building systems. These credits are also, for the most part, closely aligned with the Province's energy and GHG emission reduction objectives. However, the majority of non-mandatory energy and GHG emission related credits have experienced only low to medium uptake under the current voluntary approach, particularly with respect to buildings certified at lower levels, suggesting that voluntary application of these credits will only provide limited support towards achieving policy objectives.

5.3.2. Water

With respect to water, both rating systems again show a high degree of comparability between them in terms of coverage, including stormwater management, site enhancement practices, water conservation features and requirements for water conservation policies. With the notable exception of requirements to measure water consumption (i.e., metering and annual water audits), alignment with the province's objective of reducing water consumption by 33% by 2020 is not as clear. Requirements to measure water consumption show a high degree of correlation with rating system requirements and strong voluntary uptake by accredited buildings.

5.3.3. Waste

BOMA BESt and LEED EB:O&M have a high degree of commonality with respect to credits dealing with waste reduction, including requiring waste audits and waste reduction programs for ongoing consumables and construction and demolition wastes. However, it is estimated that these requirements would only have moderate impact on helping to achieve the Province's waste diversion targets, in part because a number of credits only require tracking of wastes and provision of storage areas, but do not set diversion targets. Only the credit associated with the recycling of ongoing consumables has received universally strong uptake to date amongst certified buildings.

6. POLICY RECOMMENDATIONS

The study presents a number of unique findings with respect to the performance of BC buildings. This section summarizes the important findings from the sample set of buildings and makes recommendations with respect to building policy development and related issues around building performance for consideration by governments and industry. While the results of this study are tentative, they do point to several conclusions that have implications for the future development of green building policy and the attainment of sustainability targets at the provincial, regional and local levels.

1. Improve access to energy consumption data from utilities

A common challenge for studies of this nature has been the difficulty in obtaining building data. In the case of this study, an inordinate amount of time and effort was expended attempting to access data from utilities and building owners. Similarly, policy makers are hampered in their efforts to develop targeted policy initiatives because of the lack of quality building performance data.

Public access to building data in British Columbia is made difficult by a number of legal and technical barriers, although the exact nature of these barriers is not entirely clear. Provincial privacy legislation and internal corporate policy is the primary reason cited by utilities for not being able to provide building data. Maintaining the privacy protections is an important principle, however the privacy of buildings, building owners and managers can be upheld while still providing utility data in aggregate form or in a way that removes building-specific identifiers. The interpretation and application of privacy law has been inconsistent across and within various utilities depending on the department or individual consulted. Some utilities, such as BC Hydro, did provide aggregate data for this study suggesting that privacy legislation is not a bar to accessing aggregate data or building-specific data in a manner that does not disclose the identification of individual buildings. However, others still cite privacy legislation as the grounds for not being able to release building data at all. In the context of this study, Fortis BC stated that it was unable to release natural gas data on the grounds that it would violate privacy legislation. Fortis BC directed the study team to its online customer portal where account holders can access data. Unfortunately, obtaining account information for each building is too costly and impractical for a study, let alone a municipality.

In addition to privacy issues, there are a number of technical barriers that make access to building data difficult. For example, it is difficult to obtain consolidated data for whole buildings, particularly MURBs. Utility accounts are tied to individual meters and civic addresses, but buildings often contain multiple addresses (e.g., main residential address and unique commercial addresses) and utilities do not appear to have a means of coding accounts so that all accounts associated with a building can be easily grouped together. There also appears to be no clear line of authority within some utilities to authorize the release of building data. These are just some of the technical challenges facing access to aggregate or anonymous building data.

The inability to obtain building performance data is handicapping the efforts of local governments to develop effective building policy. Without having accurate data on how buildings are performing, policy makers are not able to identify which types of buildings require government support and the nature and scope of that support. Municipalities, such as the City of New York, have worked closely with local utilities to devise direct means of importing utility data into Portfolio Manager® under its mandatory reporting and disclosure requirements, which is already having a tremendous influence on policy development in this area.[38]

[38] See New York City Local Law 84 Benchmarking Report, note 18 above.

Based on the experience of this study and other research requiring access to building energy consumption data, we make the following recommendations as a starting point to facilitate greater and easier access to aggregate and anonymous building energy consumption data:

- Have the Province provide a legal interpretation on the application of privacy legislation to building data. This would provide utilities and industry associations with greater comfort in the sharing of building utility data.
- Grant an exemption under Provincial privacy legislation for the release of aggregate or anonymous utility data for buildings on public interest grounds.
- Alternatively, consider having utility account holders sign a blanket disclosure granting permission at the time an account is established authorizing sharing of consumption data in aggregate form or without the building being identified. This would facilitate utilities bypassing the privacy issue entirely.
- Create a common codification system to tie accounts to a building to allow for reporting of whole building data.
- Identify one individual within each utility responsible for handing data requests to ensure consistent interpretation and application of privacy legislation and internal corporate policy in handling such requests.
- Work with and learn from the many US jurisdictions who have successfully established electronic methods for utilities to submit building utility data directly to local governments through Portfolio Manager® (Chicago, Seattle, Portland, New York, etc.).

2. Mandate and incentivize reporting of building energy, waste and water data.

Having current building consumption data is an essential first step in achieving resource reduction and GHG emission reductions in buildings. The experience of this study reflects that of many other previous efforts, namely, voluntary efforts to obtain data are extremely costly and time consuming and don’t achieve the desired results. While local utilities are making efforts to provide building data, emerging best practice points towards placing the onus on building owners to disclose and report building consumption data.

Leading jurisdictions across North America and Europe recognize that any effective strategy for addressing building performance requires an understanding of how buildings are currently performing. In the United States, nine cities and two states have mandated that all buildings (or those meeting a prescribed size threshold) disclose and report building energy data. Generally, building owners submit utility data online to ENERGY STAR Portfolio Manager® or retain a third-party consultant to do it for them. In two years, the City of New York has achieved 75% compliance with its disclosure requirements providing a rich database of building energy data.[39] Jurisdictions that have implemented mandatory reporting and disclosure of energy data for buildings are able to focus policy initiatives more effectively and realize significant savings (see e.g., New York City’s 2013 benchmarking report).

The City of Vancouver is currently considering the introduction of mandatory disclosure for all buildings. An unprecedented gathering of representatives from jurisdictions across North America that have implemented mandatory disclosure requirements was hosted by the City in 2013. This benchmarking summit provided a unique opportunity for policymakers and practitioners to share their experiences and identify means of improving their programs. Many of the challenges facing implementation were explored, including bundling whole building data, data accuracy, automatic data uploading from utilities, Portfolio Manager®’s ability to respond to the diversity of building types, and compliance.

[39] See New York City Local Law 84 Benchmarking Report, note 18 above.

For municipalities looking to implement mandatory benchmarking requirements, the greatest challenge is industry resistance. Building owners and managers are most concerned about privacy issues and the additional cost and time required to provide the data. These are valid concerns, but ones that can be addressed with current technologies and best practice. What is important is to provide building owners and managers with ample notice of the pending requirements, stagger implementation of the policy over successive years, guarantee anonymity of building data in any public reporting, and ensure a level playing field for all buildings. Specific recommendations to enable energy benchmarking in British Columbia, include:

- The Province should amend legislation as required to give local governments the authority to require disclosure and reporting of building consumption data.
- Work with utilities and ENERGY STAR Portfolio Manager® to facilitate automatic uploading of building data into Portfolio Manager®. This is particularly important in the context of stratas and multi-unit residential buildings where each unit is metered separately.
- Work with Assessment BC and utilities to develop a common codification system for grouping addresses tied to a specific building to facilitate whole building reporting.
- Whether under a voluntary or mandatory scheme, consider offering incentives to the poorest performing buildings based on energy usage intensity performance thresholds as a means of fostering higher compliance rates.. Incentives should be subject to the building entering energy data into Portfolio Manager® and making it available to the municipality and Province.

3. Mandate and/or incentivize auditing and retro-commissioning of all buildings

Benchmarking building performance through disclosure and reporting of building energy, water and waste data is an important first step in improving existing buildings by raising awareness of the current state of building performance. However, building owners and managers must maintain and upgrade building systems if significant improvements in building performance are to be achieved. Currently, there are no requirements for buildings to maintain or upgrade building systems, except to the extent that they may constitute a threat to public health and safety. For the most part, building maintenance and optimization is market driven to attract and retain tenants.[40]

The study's findings underscore the potential gains that can be achieved through ongoing maintenance and upgrading of building systems. Buildings in the study that underwent recertification showed significant improvements in performance. This was likely attributable to a number of factors, including heightened awareness about a building's environmental performance and potential cost savings through the process of certifying and a desire to improve on that performance and the building's market profile when recertifying.

However, despite the noticeable improvements achieved amongst BOMA BESt recertified buildings, these buildings represent a very small fraction of buildings in the Province. While market forces should encourage building owners and managers to undertake these activities voluntarily, issues such as split incentives and short-term ownership strategies, result in many buildings failing to undertake these measures, or at best, doing them on an ad-hoc, system-specific basis to address urgent problems. Findings for the rest of the buildings in the study support findings from previous studies and reports that buildings are not performing optimally and there is significant room for improvement in building performance. This consistent finding across the literature suggests that a strictly voluntary market-driven approach will be insufficient to achieve the policy

[40] Fortis BC has been offering free energy assessments for medium sized businesses and small industrial/manufacturing operations. See Fortis BC Commercial Energy Assessment Program at http://www.fortisbc.com/NaturalGas/Business/SavingEnergy/CommercialEnergyAssessmentProgram/Pages/default.aspx.

objectives identified by the Province with respect to GHG emission reductions, and energy, waste and water conservation.

A building energy audit allows a building owner or manager to identify the specific source of any underperformance observed through benchmarking. ASHRAE provides three levels of energy with the first level involving a building walk through and high level recommendations.[41] Level 1 audits typically identify major problems. A Level 2 energy audit includes payback calculations on all major energy consuming equipment and systems including the building envelope, while a Level 3 energy audit includes full scale building energy modelling and simulation using approved modelling software. Retro-commissioning (RCx) is the process of recalibrating or replacing building systems to ensure they are performing optimally. While best practice suggests that building audits should be undertaken annually followed by RCx, jurisdictions that have mandated audits and retro-commissioning (e.g., New York City and Austin, Texas) generally require audits be undertaken every 5 or 10 years. Austin's Energy Conservation Audit and Disclosure (ECAD) Ordinance (2009, revised in 2011) establishes tenant energy disclosure and audit requirements for residential multi-family buildings, as well as benchmarking requirements for commercial buildings. In its first year of implementation (2011), the City of Austin reported that its audit requirement achieved a 53% compliance rate (574 apartment communities comprising 4,309 individual apartment buildings). Audits identified an average rate for duct leakage of approximately 40% evidencing the importance of auditing and RCx.[42] These requirements are also anticipated to generate significant employment opportunities for energy auditors and commissioning agents.

Similar challenges identified for building benchmarking exist with respect to implementing policy on building audits and RCx requirements. Experience points to the need for a level playing field for all buildings and standardized approaches to undertaking audits and reporting findings, as well as an incremental and supportive approach to introducing these approaches to the building sector.

Similar to the recommendations for disclosure and reporting, the study recommends the following steps to advance building auditing and retro-commissioning across the Province:

- Have the Province amend legislation as required to give local governments the authority to require building owners to undertake building energy audits and retro-commission buildings.
- Through the cooperation of the Province, local governments and utilities, begin by augmenting incentives for energy audits of all buildings.
- Introduce graduated requirements for buildings to undergo audits and retro-commissioning. Increase scope of buildings captured over time by size or performance level as determined through mandatory reporting.

4. Consider rating systems at the credit level

As noted in the discussion on green building rating systems in this study (see section 5.2 above), both the Province and local governments across British Columbia have followed a trend initiated in the United States, adopting green rating systems, particularly LEED for New Construction, as part or all of the their green building policy pertaining to new construction. While this approach has raised the profile of green building and engendered greater acceptance of green building principles into the construction process, it has resulted in inconsistent levels of improvement in building

[41] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Procedures for Commercial Building Energy Audits (2nd ed.). 2011.
[42] Commission on Environmental Cooperation, *Recipes for the Redensification of Cities and the Growth of Green Buildings in North America* (Anticipated publication date 2014). Copy available from Light House.

performance. This, in turn, has resulted in buildings that may or may not meet specific building performance targets set by government.
Many factors contribute to these inconsistent outcomes. One reason is that third party rating systems allow significant discretion in the selection of credits and the credits selected on a project may not yield performance outcomes that accord with policy priorities. Furthermore, while specific credits within both BOMA BESt and LEED EB:O&M are strongly aligned with government targets for GHG emission, energy, waste and water reduction, others are not. In short, as long as building owners and managers have the ability to select the credits or points they wish to pursue with no prerequisites or minimum mandatory requirements, it is not possible to rely on third party rating systems to guarantee a certain level of performance from a building.

In response to this, the City of Vancouver has made a number of optional LEED NC credits mandatory in the context of new construction to ensure that projects are meeting municipal objectives.[43] Specifically, all new construction projects are required to achieve 6 optimized energy performance credits, 1 water efficiency credit, and 1 stormwater credit, all of which would otherwise be optional for a LEED NC project.

Preliminary findings suggest aligning public policy with specific rating system requirements can provide a streamlined approach to achieving desired performance outcomes while also minimizing administrative burdens for municipalities and the building sector. However, regardless whether a jurisdiction is considering the adoption of a rating system for existing buildings, such as BOMA BESt or LEED EB:O&M, or developing its own unique set of requirements and merely looking to align its policy with third-party rating systems, the findings of this study and the experience of many local governments is that consideration of third-party rating system requirements must take place at the *credit level*. Appendix C assesses the degree of alignment between specific BOMA BESt points and LEED EB:O&M credits with Provincial policy objectives. The results show significant variations in the degree of alignment between specific credits and Provincial targets for energy, waste, water and GHG emissions. For example, optional credits/points for optimizing and upgrading HVAC, lighting and other systems under both rating systems are considered to be highly aligned with the Province's objectives to reduce average energy demand per home by 20% by 2020 and energy demand at work by 9% per sq. metre by 2020, whereas credits/points associated with light pollution reduction are not. Therefore, governments considering the incorporation of third-party rating systems into their green building policy framework for existing buildings are best served by taking a credit-level approach.

In considering the adoption of third-party rating systems, governments also need to consider whether the specific aspect of building performance is best served by a performance-based or prescriptive standard. Rating systems offer a combination of performance-based and prescriptive elements which vary across systems. Again, each government must evaluate which approach is appropriate given its unique context.

5. Focus attention and support on Class B and C office buildings and residential buildings

The study's findings highlight the challenge that many governments have in identifying building owners and managers of tier B and C office buildings and residential buildings, and supporting performance improvements amongst these classes of buildings. There have been many barriers to engaging owners and managers of these buildings, including the lack of any public registry of building owners and managers, challenges in providing a convincing business case for improving building performance, high turnover rates in ownership, low energy prices, and the "split incentive" dilemma where tenants bear the costs for tenant improvements and utilities.

[43] City of Vancouver, *Green Buildings Policy for Rezonings* (adopted July 22, 2010). Available at http://former.vancouver.ca/commsvcs/guidelines/G015.pdf.

In addition, local governments are limited by legislation in terms of the type of support they can offer businesses. Specifically, regional governments and municipalities are limited in the type of direct financial incentives they can provide to businesses to support performance improvements (see e.g., section 25.1 of the *Community Charter* with respect to municipal corporations).

The experience compiling data for this study bears out the experience of local governments and industry associations in British Columbia generally, namely, that efforts to address building performance to date have focused on Class A and, to a lesser extent, Class B buildings. However, the fact is that many Class A buildings are already considered high-performing buildings. Furthermore, most are owned by larger property owners or institutional investors that have rigorous operating maintenance programs in place and have received recognition for their efforts under BOMA BESt and LEED EB:O&M. Accordingly, governments, utilities, industry associations and others advocating for efficient buildings need to focus policy initiatives at addressing the performance of Class B and C office buildings, as well as residential buildings, many of which are older and managed by smaller entities.

7. Appendix A: Benchmarks

This appendix will set out the various benchmarks referenced in this study and provide a brief summary of their scope and approaches.

NRCAN. National Comprehensive Energy Use Database Query System for Office, Retail and Industrial energy usage intensity values (2012). [44]

Natural Resources Canada conducts an annual survey on energy use in buildings across Canada, the results of this survey are published in the NRCAN Comprehensive Energy Use Database[45]. For commercial buildings, the Database relies on data from the following sources:

- Statistics Canada, *Report on Energy Supply-Demand in Canada, 1990-2010*, Ottawa, 2012.
- Natural Resources Canada, *Commercial/Institutional End-Use Model*, Ottawa, 2012.
- Statistics Canada, *Electric Power Generation, Transmission and Distribution, 2006-2010*, Ottawa, 2012 (Cat. No. 57-202-X).

For residential buildings, the Database relies on the following data sources:

- Statistics Canada, *Report on Energy Supply-Demand in Canada, 1990-2010*, Ottawa, 2012.
- Natural Resources Canada, *Residential End-Use Model*, Ottawa, 2012.

For the purpose of this study, the national and BC and Territories average EUI values were used as primary benchmarks to evaluate building energy performance (see Table 12).

EUI measured in ekWh/m²/yr	All buildings	Offices	Retail Trade	Accommodation and Food Services	Transportation and Warehousing	Other Services
Canada	406	347	425	622	336	381
Atlantic	306	264	331	464	206	253
Quebec	461	378	467	733	383	428
Ontario	414	353	428	617	358	403
Manitoba	433	375	469	708	339	411
Saskatchewan	494	450	578	661	372	450
Alberta	436	383	486	706	375	383
BC and Territories	**308**	**272**	**294**	**486**	**247**	**306**

Table 12: NRCAN Building Energy Use Intensity Benchmark Values for Commercial and Institutional Buildings (2010)

[44] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/query_system/querysystem.cfm?attr=0
[45] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/comprehensive_tables/list.cfm?attr=0

BOMA Canada. BOMA BESt Energy and Environmental Report (2013).[46]

BOMA Canada conducts an annual building performance survey for BOMA BESt certified buildings. The 2013 BOMA BESt Energy and Environment Report (BOMA BEER) analyzed aggregate energy, water and waste data for 455 buildings certified under BOMA BESt Levels 2,3, and 4 in 2012. Level 1 certified buildings were not included. BOMA BEER used NRCAN's national average for energy use intensity in evaluating the performance of certified buildings across the country.[47]

NRCAN. Survey of Household Energy Use (2007).[48]

The 2007 Survey of Household Energy Use survey single family homes and multi-unit residential properties on a variety of energy related information, including:

- the use of selected energy-consuming equipment and appliances
- energy-related characteristics of dwellings
- household demographics
- patterns of behaviour related to consumption
- amounts of energy consumed during the reference period

Data on the age and size of the dwelling, dwelling conditions, improvements and types of heating and cooling equipment were also collected. The survey was administered between October 2007 and February 2008 to 9,776 dwellings.

RDH Building Engineering. Energy Consumption and Conservation in Mid and High Rise Residential Buildings in British Columbia (2012). [49]

This study surveyed data for 39 MURBs in Vancouver and Victoria representing approximately 4,400 suites with 4.6 million square feet of gross floor area. The study obtained 10 years of utility data for each building to account for climatic variations, including at least 2-3 years of data post-retrofit.

FRESCo. *Energy Labelling in Multi-Unit Residential Buildings (2013).* [50]

This study evaluated the performance of 41 MURB facilities comprising 52 buildings in Metro Vancouver. The sample included a diverse range of buildings ranging in age (5 to 62 years) and height (low, mid and high rise), as well as low-income and non-profit housing to high-end condominiums and MURBS owned by a single entity and independent unit ownership. ENERGY STAR Portfolio Manager® was used to provide normalized site and source EUIs.

REALpac. Water Benchmarking Study (2011).

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[46] BOMA Canada, *supra.*
[47] BOMA Canada, *BOMA BESt Energy and Environment Report 2013*. Available at http://www.bomabest.com/wp-content/uploads/BBEER-2013-Full-Report.pdf.
[48] http://oee.nrcan.gc.ca/Publications/statistics/sheu07/index.cfm
[49] http://www.hpo.bc.ca/sites/www.hpo.bc.ca/files/download/Report/MURB-EnergyStudy-Report-Executive-Summary.pdf
[50] Fresco, *supra.*

This study analyzed water utility data for 74 commercial and administrative buildings from across Canada.

New York City Benchmarking Report September 2013[51]

New York City's Benchmarking Report documents the performance of all buildings in the City over 10,000 ft^2. under the City's mandatory benchmarking requirements. The 2013 report captured data for 7,505 multi-family, 1,150 office and 1,226 "other" properties. Data was analyzed using Portfolio Manager®.

New York City's Benchmarking Report for 2013 was considered in developing the study's methodology. NYC's findings were not used for comparison purposes because of the differences in the report's building stock.

[51] See New York City, Local Law 84 Benchmarking Report (September 2013) at footnote 18 above.

8. Appendix B: Alignment of Third-Party Rating Systems with Policy Objectives

Energy

Indicator	Policy Objectives	BOMA BESt Credit	Points	% of total points	LEED EB:O&M Credit	Points	% of total points	Alignment between BOMA BESt & LEED EB:O&M	Alignment with Policy Objective	BOMA BESt Credit Popularity			LEED EB:O&M Credit Popularity			
										Level 2	Level 3	Level 4	Cert	Silver	Gold	Platinum
Energy & CO2	Reduce GHG emissions by 33% by 2020 from 2007 levels. Reduce GHG emissions by 80% by 2050 from 2007 levels. Make government buildings carbon neutral by 2010	Environmental Management System (Energy conservation policy)	7	0.70%	EAc6: Emissions Reduction Reporting (Annual reporting of GHGs)	1	0.90%	high	high	N/A	N/A	N/A	<33%	<33%	33-66%	>66%
		Public Transportation Cycling Facilities Innovation (Proximity to alternative commuting options, carshare parking, bike parking.)	60	6.00%	SSc4: Alternative Commuting Transportation (Alternative commuting survey).	15	13.64%	high	high	33-66%	>66%	>66%	<33%	33-66%	>66%	>66%
		Green Leases	5	0.50%	N/A	N/A	N/A	low	med	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Renewable Energy (Purchase green power or generate renewables on-site).	12	1.20%	EAc4: On-Site And Off-Site Renewable Energy (Purchase green power or generate renewables on-site).	6	5.50%	high	high	N/A	N/A	N/A	<33%	<33%	<33%	>66%
	Reduce average energy demand per home by 20% by 2020. Reduce the energy demand at work by 9% per sq. metre by 2020	Site enhancement (Outdoor lighting is shielded).	3	0.30%	SSc8: Light pollution reduction.	1	0.90%	high	low	N/A	N/A	N/A	>66%	<33%	33-66%	>66%
		Documented Operating Instructions (Operating instructions manual).	5	0.50%	EAp1: Energy Efficiency Best Management Practices. (Building operating plan).	P	P	high	high	N/A	N/A	N/A	Mandatory			
		Energy Training (Operator energy training).	5	0.50%	EAc2.2: Commissioning: Implementation (Operating training).	2	1.80%	high	med	>66%	>66%	>66%	>66%	33-66%	33-66%	>66%

Indicator	Policy Objectives	BOMA BESt Credit	Points	% of total points	LEED EB:O&M Credit	Points	% of total points	Alignment between BOMA BESt & LEED EB:O&M	Alignment with Policy Objective	BOMA BESt Credit Popularity			LEED EB:O&M Credit Popularity			
										Level 2	Level 3	Level 4	Cert	Silver	Gold	Platinum
		Energy Efficiency Features: Lighting (Upgrade lighting & lighting controls).	26	2.60%	EAc1: Optimize Energy Performance (ENERGY STAR rating above 69).	18	16.40%	high	high	>66%	>66%	>66%	Avg 6 points	Avg 8 points	Avg 11 points	Avg 13 points
		Major HVAC Equipment (Upgrade mechanical equipment: boilers, chillers, vent dampers).	25	2.50%	EAc1: Optimize Energy Performance (ENERGY STAR rating above 69).	18	16.40%	high	high	33-66%	33-66%	>66%	Avg 6 points	Avg 8 points	Avg 11 points	Avg 13 points
		Other Energy Efficiency Systems (VSD, VFD, HRV, economizers on boilers).	8	0.80%	EAc1: Optimize Energy Performance (ENERGY STAR rating above 69).	18	16.40%	high	high	33-66%	33-66%	>66%	Avg 6 points	Avg 8 points	Avg 11 points	Avg 13 points
		Controls (BAS)	11	1.10%	EAc3.1: Building Automation System	1	0.90%	high	high	>66%	>66%	>66%	>66%	33-66%	33-66%	33-66%
		Q1: Energy Audit (ASHRAE Level 1 energy audit).	P	P	EAp1: Energy Efficiency Best Management Practices. (ASHRAE Level 1 energy audit).	P	P	high	med	Mandatory for both rating systems						
		Q2: Energy Management Plan & Reduction Targets.	P	P	EAc2.1: Commissioning: Investigation & Analysis (Retro-commissioning low-cost & capital cost energy efficiency measures).	2	1.80%	high	med	Mandatory			>66%	33-66%	>66%	>66%
		Q14: Environmental Communication With Tenants	P	P	N/A	N/A	N/A	low	low	Mandatory			N/A	N/A	N/A	N/A
		Envelope (Building envelope optimization measures: windows, reflective film, air sealing).	32	3.20%	N/A	N/A	N/A	low	med	>66%	>66%	>66%	N/A	N/A	N/A	N/A
		Financial Resources (Energy efficiency budget).	5	0.50%	N/A	N/A	N/A	low	low	N/A	N/A	N/A	<33%	<33%	med 33-66%	med 33-66%

Indicator	Policy Objectives	BOMA BESt Credit	Points	% of total points	LEED EB:O&M Credit	Points	% of total points	Alignment between BOMA BESt & LEED EB:O&M	Alignment with Policy Objective	BOMA BESt Credit Popularity			LEED EB:O&M Credit Popularity			
										Level 2	Level 3	Level 4	Cert	Silver	Gold	Platinum
		N/A	N/A	N/A	EQp1: Minimum IAQ Performance (Ventilation volumes to meet ASHRAE 62.1-2007).	P	P	low	high	N/A	N/A	N/A	Mandatory			
		N/A	N/A	N/A	EQc1.2: IAQ Best Management Practices: Outdoor Air Delivery Monitoring (Monitor outdoor air delivery via CO2 sensors & BAS monitoring).	1	0.90%	low	med	N/A	N/A	N/A	<33%	>66%	>66%	>66%
		Sub-Metering (Energy sub-metering).	10	1%	EAc3.2 & 3.3: Performance Measurement (Energy sub-metering) Energy sub-metering.	2	1.80%	high	med	33-66%	33-66%	>66%	<33%	<33%	33-66%	>66%
		Maintenance And Commissioning.	33	3.30%	EAc2.3: Ongoing Commissioning.	2	1.80%	high	high	N/A	N/A	N/A	<33%	<33%	33-66%	33-66%
		Environmental Purchasing (HVAC & appliance environmental purchasing).	5	0.50%	MRc2.1: Sustainable Purchasing Policy: Durable Goods - Electric Equipment (Appliance environmental purchasing).	1	0.90%	high	med	N/A	N/A	N/A	>66%	>66%	<33%	>66%

* N/A = Not available.

WATER

Indicator	Policy Objectives	BOMA BESt Credit	Points	% of total points	LEED EB:O&M Credit	Points	% of total points	Alignment between BOMA BESt & LEED EB:O&M	Alignment with Policy Objective	BOMA BESt Credit Popularity			LEED EB:O&M Credit Popularity			
										Level 2	Level 3	Level 4	Cert	Silver	Gold	Platinum
Water	Reduce water use by 33% by 2020 & 50% of new municipal water needs addressed through conservation by 2020	Site Enhancement (Low-impact site & exterior building cleaning).	4	0.40%	SSc2: Building Exterior & Hardscape Management Plan (Low-impact site & exterior building cleaning).	1	0.90%	high	low	N/A	N/A	N/A	<33%	>66%	>66%	>66%
		Site Enhancement (Stormwater management).	3	0.30%	SSc6: Stormwater Quantity Control.	1	0.90%	high	high	N/A	Not Avail	N/A	<33%	<33%	<33%	>66%
		Water Consumption (Measuring water consumption).	30	3%	WEp1: Water Metering And Minimum Indoor Plumbing Fixture & Fitting Efficiency (Annual water audits).	P	P	high	high	>66%	>66%	>66%	Mandatory			
		N/A	N/A	N/A	SSc3: Integrated Pest Management, Erosion Control And Landscape Management Plan (Low-impact landscape management).	1	0.90%	low	low	N/A	N/A	N/A	>66%	>66%	>66%	>66%
		Water Conserving Features (Low-flow plumbing fixtures).	30	3%	WEc2: Additional Plumbing Fixture And Fitting Efficiency (Low-flow plumbing fixtures).	5	4.50%	high	med	33-66%	>66%	>66%	>66%	>66%	33-66%	>66%
		Water Conserving Features (Non-potable water in cooling towers).	3	0.30%	WEc4.2: Cooling Tower Water Management: Non Potable Water Source	1	0.90%	high	med	N/A	N/A	N/A	<33%	<33%	<33%	<33%
		Water Conserving Features (Cooling tower automated controls).	4	0.40%	WEc4.1: Cooling Tower Water Management: Chemical Management	1	0.90%	high	med	N/A	N/A	N/A	<33%	>66%	>66%	<33%
		Q4: Required Water Conservation Policy	P	P	WEc1: Water Performance Measurement (Water sub-meters).	2	1.80%	high	med	>66%	>66%	>66%	>66%	<33%	33-66%	>66%
		Water Conserving Features (Non-potable water for irrigation & high-efficiency equipment).	6	0.60%	WEc3: Water Efficiency Landscaping (Non-potable water for irrigation & high-efficiency equipment).	5	4.50%	high	med	N/A	N/A	N/A	>66%	33-66%	<33%	>66%

WASTE

Indicator	Policy Objectives	BOMA BESt Credit	Points	% of total points	LEED EB:O&M Credit	Points	% of total points	Alignment between BOMA BESt & LEED EB:O&M	Alignment with Policy Objective	BOMA BESt Credit Popularity			LEED EB:O&M Credit Popularity			
										Level 2	Level 3	Level 4	Cert	Silver	Gold	Platinum
Waste	Require Regional Districts to prepare & submit solid waste management plans. Reduce quantity of waste generated per capita within the region to 90% or less of 2010 volumes by 2020. Increase diversion rate to 70% by 2015 and an aspirational target of 80% by 2020. The 70% diversion is divided by sector: Multi family 30%, single family 65%, ICI 70%, and D&C 80%.	Hazardous Materials Survey (Includes management plans).	45	4.50%	MRp2: Solid Waste Management (Appropriate disposal of hazardous waste).	P	P	low	low	Mandatory for both rating systems						
		Q11: Required Hazardous Products Management Plan	P	P	No equivalent credit	N/A	N/A	low	low	Mandatory			N/A	N/A	N/A	N/A
		Recycling, Storing & Handling Recyclable Materials (Waste reduction program & facilities).	25	2.50%	MRp2: Solid Waste Management (Appropriate disposal of hazardous waste).	P	P	high	low	>66%	>66%	>66%	Mandatory			
		Waste Reduction Program (Annual waste audit).	5	0.50%	MRc6: Waste Audit	1	0.90%	high	med	33-66%	>66%	>66%	>66%	>66%	>66%	>66%
		Waste Reduction Program (Ongoing waste monitoring).	15	1.50%	MRc7: Solid Waste Management: Ongoing Consumables	1	0.90%	high	med	>66%	>66%	>66%	>66%	>66%	>66%	>66%
		No equivalent credit	N/A	N/A	SSc3: Integrated Pest Management, Erosion Control And Landscape Management Plan (Landscape waste tracking).	1	0.90%	low	med	N/A	N/A	N/A	>66%	>66%	>66%	>66%
		Recycling, Storing & Handling Recyclable Materials (Composting).	5	0.50%	MRc7: Solid Waste Management: Ongoing Consumables	1	0.90%	low	med	33-66%	33-66%	>66%	>66%	>66%	>66%	>66%
		Q7: Construction Renovation And Demolition Waste	P	P	MRc9: Solid Waste Management: Facility Alterations & Additions (Plan & tracking).	1	0.90%	high	low	Mandatory			>66%	<33%	<33%	33-66%

* N/A = Not available.

I writing to OPPOSE the ***CD-1 Rezoning at 1477 West Broadway.*** City Council must ensure that decisions are being made that benefit the citizens of Vancouver. But the theme of this proposal is that it does not benefit the citizens of Vancouver.

1. Broadway Plan: 7 times throughout the Report, **City staff state that the proposed height and density of the proposal aligns with the Broadway Plan Refined Directions, even though the Broadway Plan is not finished, nor has it been approved by Council.** This demonstrates that the City is only paying lip service to the public through the Broadway Plan consultation, thereby ignoring the input of the public, and not concerning itself with what is for the ***benefit the citizens of Vancouver.***

2. Sacrificing Millions of Dollars: **The developer (PCI) has applied for a Development Cost Levy waiver (saving $3.3M) and will not have to make any financial Community Amenity Contributions, the money used to pay for parks, childcare facilities, social housing, infrastructure, etc.** If, as the report suggests, there will be 43 MIRHPP units, that equates to a subsidy of more than $77,000 per unit. Residents should not lose sight of the fact that this is revenue that the City will not be receiving – and will have to make this up elsewhere – meaning your property taxes. ***This does not benefit the citizens of Vancouver!***

3. Not green: Staff claims that this is a "green" building, but Brian Palmquist's recent analysis shows that **the COV's Sustainability standards are, in some cases, non-existent, nor do they contemplate the full lifecycle GHG emissions of buildings, including construction and materials.** City staff remains stuck in the false narrative that bigger is better, yet tall towers such as this have been shown to have a greater negative impact on the climate than smaller buildings. The recommendation of this 39-storey building does not align with scientific and real-life evidence. Doesn't Vancouver claim to be a green City and have aspirations of continuing to do so? If so, this building cannot be part of Vancouver's future, because as a significant contributer to GHG, it ***does not benefit the citizen of Vancouver!***

4. Homes for Families: **How much sense does it make to have family-oriented housing in a high-rise located at one of the busiest intersections in the City of Vancouver, and where the subway station will generate a very high volume of foot traffic?** Has any thought been given to the possibility that this might not be the ideal location for children since, even if they want to go to Granville Park, it's 0.5km away and requires walking down busy streets and navigating through transit-related pedestrian traffic and queues? ***This does not benefit the citizens of Vancouver, specifically the families that are suggested to live there.***

5. Schools: This rental building is being planned for all family types and yet **the Report provides no details on the building's amenities, access to parks, nor space in nearby schools (catchment schools and other nearby schools have no capacity).** Under the section headed "Council Authority/Previous Decisions" staff have cited the "High-Density Housing for Families with Children Guidelines" as part of the justification for this project. The guidelines stipulate that "sites selected for family housing development should be within 0.8 km walking distance of an elementary school". False Creek Elementary School is 1.3km from Broadway and Granville. Henry Hudson Elementary school is a distance of 1.6km. **Not only are the closest schools further away than the Guidelines instruct, these are both operating at full capacity!** Building homes for families where there are no available neighbourhood schools for their children. ***This does not benefit the citizens of Vancouver.***

6. Through escalating property values, the rezoning will place immense pressure on the large number of older, affordable rentals in the neighbourhood, exacerbating our housing affordability crisis.

***Who does this plan benefit*?** The evidence shows that it certainly does not benefit the citizens of Vancouver. For these reason, I oppose this development, and I urge you to vote against it. Thank you.

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