The Urgent Quest to Decarbonize Seattle's Skyline: Technologies and Barriers

Olivia Killian

In recent years, there has been a push to move toward electric transportation, creating energy through clean and renewable sources, and decreasing our carbon footprint in producing and manufacturing goods. Although these are all essential actions, commercial and residential building emissions, in addition to the life-cycle impacts of a building, account for about 40% of all global energy-related greenhouse gas emissions [1]. Cities, towns, and buildings are constantly expanding or being remodeled, presenting an opportunity for considerable improvements in global, national, and local greenhouse gas (GHG) emissions. Also, since buildings have a much longer lifespan than vehicles and other consumer products and are more difficult to renovate to fit greener standards, we must begin fixing the environmental problems surrounding construction and buildings now. This would ensure that in the future, we will have already locked carbon emissions in these buildings and will not need to renovate all buildings to fit the net-zero emissions many countries hope to reach.

Today, we are seeing more strides to decrease the impact of construction and buildings on the environment. Still, these innovations are not widespread and, in some cases, too expensive to be an effective solution. However, with more research, use, and availability, these improvements to construction technologies and building technologies can replace conventional standards that are destructive to our environment. In addition, many local governments are creating programs to incentivize sustainable building practices. One city in particular is the City of Seattle. Seattle is among some of the fastest-growing urban areas in the country, and in 2022, it was the fastest-growing city among the nation's 50 largest cities [2]. Seattle is an example of why we must start implementing greener building strategies before more greenhouse gasses are released into the atmosphere due to its rapidly growing size. The city is already one of the few cities that have implemented more sustainable building strategies and lower carbon emissions throughout the whole city [3]. Furthermore, the city ranks in the top one percent in the country for renewable energy, making the existing buildings already significantly more sustainable due to sourcing energy from renewable sources like hydropower [3]. Even though Seattle is considered among the greenest cities in the United States, many improvements must be made in the construction and operating building industries.

Among some possible solutions for the construction industry's sizable environmental impact, multiple materials such as wood, concrete, and steel have received much attention regarding how they can be improved or used as a more efficient solution. Concrete and steel contribute largely to a building's total GHG emissions but are becoming more sustainable with research and further development of more energy-efficient processes during their production. Wood, however, is already more sustainable than concrete, and steel and new kinds of wood are being engineered to create viable wood options for large buildings. Furthermore, different heating and cooling systems can be implemented to reduce energy consumption and the burning of fossil fuels, such as heat pumps, radiant heating, and heat recovery systems. Finally, a more commonly used solution would be using on-site renewable energy for the buildings and purchasing off-site renewable energy or renewable energy credits. This option, however, will be discussed later in the form of a case study.

As illustrated in Figure 1, globally, the built environment accounts for about 39% of annual emissions, roughly 28% from the energy required for existing buildings, and 11% from materials and the construction needed to build the building [1]. In 2021, 35% of the United States' emissions came from buildings alone. Out of all the emissions in that year, 30% came from the buildings operating emissions, and 5% came from emissions known as embodied carbon emissions [4] (see Figure 2). Embodied carbon emissions include the transportation of building materials to the construction site, as well as operational emissions from machinery, which contributes more to the overall carbon emissions of each building. Embodied carbon usually accounts for as much as 50% of the whole building's emissions, so it is a significant problem to tackle by finding alternative materials and strategies to lower the emissions produced while constructing the building [5].

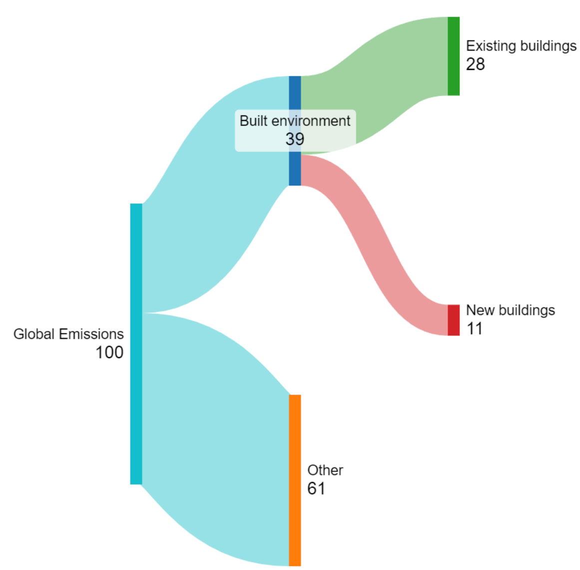

Figure 1: Percentage of built environment emissions from global emissions

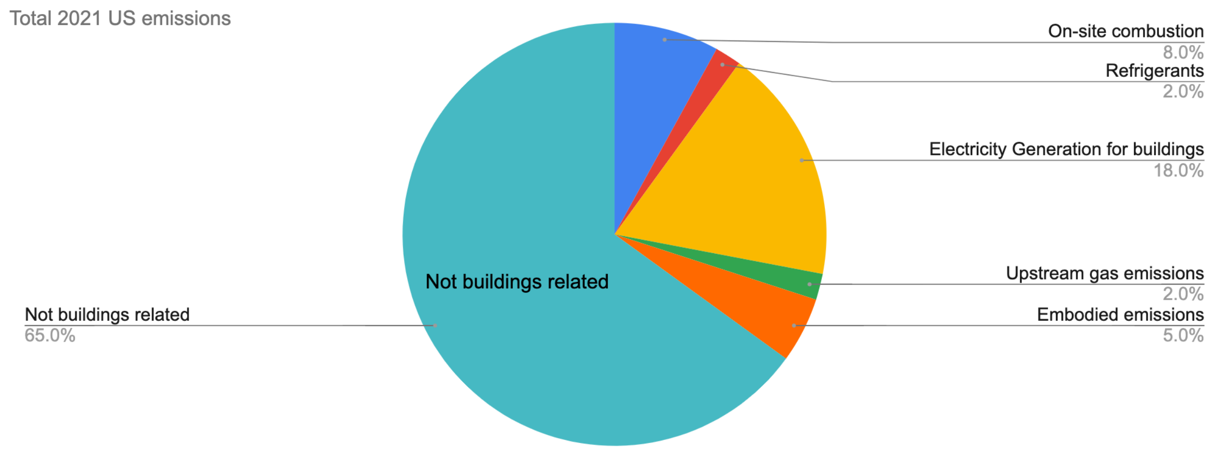

Figure 2: Breakdown of US 2021 total emissions for building related emissions

In Seattle, the emissions from buildings account for a little over a third of Seattle's total emissions, including both embodied carbon and operating emissions [2]. Of the operating emissions, 90% come from space heating, hot water, appliances, and cooking [2]. In 2020, Seattle emitted 1.14 million tons of CO_2 through existing buildings, which was a 5.2% decrease from 2018 levels [6]. For perspective, an average car emits about 4.6 metric tons of CO_2 per year, so 1.14 million tons of CO_2 is a significant amount [7]. Although these emissions are not the lowest in the country when compared to other major cities, they are definitely not the most. This is because 86% of Seattle's power comes from hydroelectric sources, and 5% comes from wind, meaning very little of the electricity in buildings comes from non-renewable sources, as illustrated in Figure 3 [8].

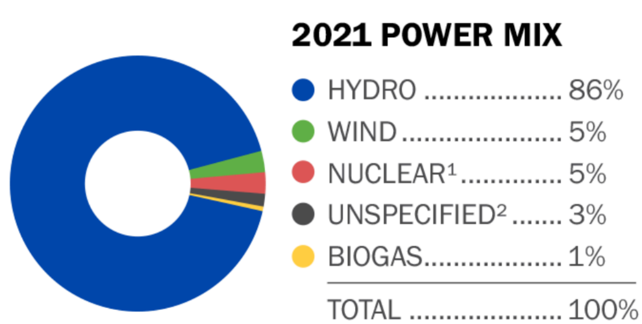

Figure 3: Seattle's electricity breakdown, note that most of the power comes from renewable sources [8].

Of the building emissions in Seattle, 55% come from commercial buildings, even though over 60% of the buildings in Seattle are residential [5]. After commercial buildings, low-rise multifamily, university, and other unspecified buildings account for about a third of the emissions originating from buildings [5]. So, if looking at what buildings need to be improved the most due to their lack of efficiency, commercial buildings are by far the least efficient. When looking at

Figure 4 and where the emissions are coming from in a commercial building, 30% come from space heating, cooling, and ventilation, 32% from cooking, appliances, electronics, and lighting, 4% from water heating, and 34% from unspecified sources [9]]. Ultimately, heating and cooling are the most essential areas for improvement, in addition to electricity and energy being used for cooking.

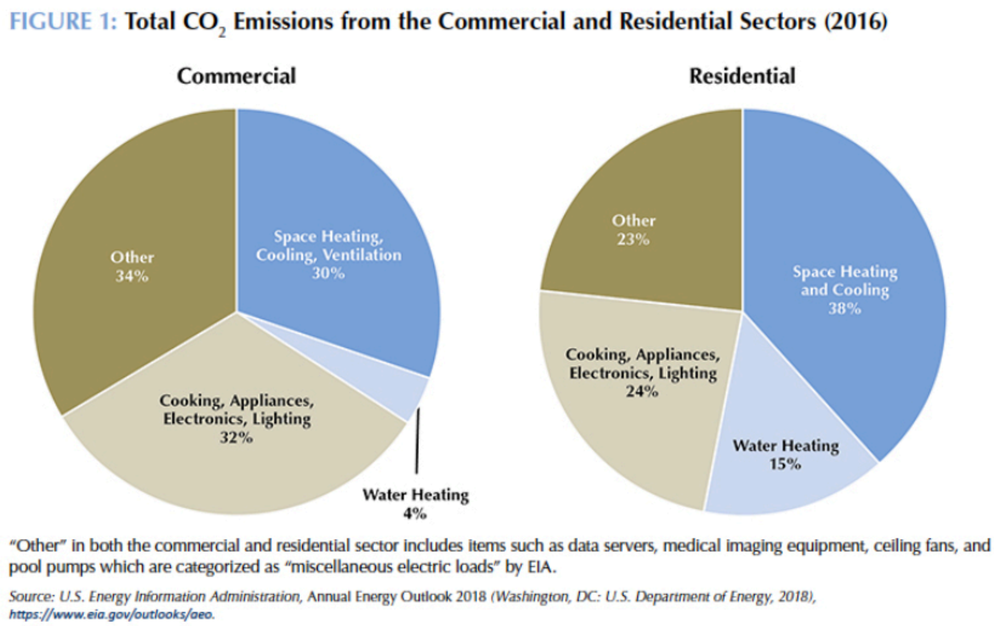

Figure 4: Description of building emissions sources and comparison between commercial and residential emissions [9].

According to the City of Seattle's webpage, the city updates its energy codes for non-residential commercial and taller residential buildings every three years to make them more efficient. The code applies when buildings are being built or undergoing major renovations and when space and water heating systems are being replaced. Seattle's GHG emissions are still increasing overall, but the hope is that the robust energy codes will help to stunt these emissions. Currently, Seattle is using the 2021 code, which has become effective recently. The 2021 code will eliminate fossil fuels like gas and electric resistance from most water and space heating systems. It will also improve building exteriors to better energy efficiency and comfort and create more opportunities for solar power. This year, a new code will be drafted and implemented in 2027 [10].

In addition to energy codes required for non-residential commercial and tall residential buildings, the City of Seattle also offers financial and other incentives to encourage sustainable building practices. Buildings that meet the requirements for different loans or funding may be eligible for financial incentives to build the buildings. These requirements span across many other types of buildings in different locations, sizes, or uses. Many incentives are given to buildings that house non-profit organizations, further encouraging beneficial practices. The funding ranges from a minimum of $5,000 to some incentives with no maximum when certain energy and water efficiency, electrification, solar and renewable energy, and seismic upgrades are met [11].

The City of Seattle offers additional, non-financial incentives, including fast building permit review and processing for new construction projects that meet building requirements, focusing on clean energy, resource conservation, indoor air quality, and lead hazard reduction. They also incentivize sustainable building by giving additional development capacity in exchange for meeting certain sustainability requirements. However, this is only offered in certain zones of Seattle due to height and area restrictions, landmarks, and neighborhood regulations. The City also extends additional height, floor area ratio, and design review departure requests for certain buildings. One requirement some of these programs take into account is low-carbon transportation to the building for the employees, which tackles issues other than the building emissions themselves [11].

Due to the push for greener construction and buildings, either through government incentives or a higher sense of importance for more sustainable practice, people have begun to develop technologies that prioritize fewer GHG emissions. A vital component of this search for better construction practices includes finding solutions that are also cost-friendly, which may be the most important factor to many people and is a complex problem to solve. Although we might be far from cost-friendly and fully zero-carbon construction practices, many options serve as promising solutions. For example, wood is becoming a viable substitute for concrete in buildings; specifically, mass timber is becoming increasingly popular. Researchers have been finding ways to decarbonize the production of concrete and steel, increase energy efficiency, and decrease reliance on fossil fuels for heating practices. It is important to note that for a building to be truly sustainable, it must rely on renewable energy for electricity, which can come from various sources. Although this last point is a very important conversation, it is already a well-researched topic and will not be discussed in this article. However, for more information, an article by Chen et al. (2023) details possibilities for renewable energy in buildings.

Wood has many benefits as a possible substitute for decreasing reliance on concrete and steel. First, wood buildings can last 100 years or more [12], compared to 50 years for concrete, spreading out the embodied emissions over a longer span. Its reliability and familiarity are some of its most promising features. Wood has been the primary building material for humans, dating back to the first creation of structures. Now, mass timber is becoming more common in the construction industry. Mass timber is wood that has been layered and pressed together to create an extremely durable, fire- and earthquake-resistant material. In Seattle, mass timber is a viable option for low-carbon building materials. Already, some buildings in Seattle use mass timber in their design. Arguably, the most sustainable building in Seattle, the Bullitt Center, used almost exclusively mass timber in its construction.

If wood is sustainably sourced from a forest, especially one relatively close to its building source, it emits significantly less GHG emissions than conventional concrete and steel [12]. If the wood is sourced from a forest near the building site, less carbon will be emitted due to transportation. During the lifetime of wood, it stores carbon instead of producing it as concrete and steel production does. While it is being used in the building, it will continue to store that carbon. After the building is no longer usable, the wood can be recycled into new materials or other wood forms such as livestock bedding or paper. However, this practice is not widely used, and wood is commonly buried in a landfill, producing a very harmful GHG, methane, in the wood's decomposition [13]. Just as the use and building of structures produce greenhouse gasses, demolition also produces large amounts of CO_2, accounting for 42.9% of all CO_2 emissions originating from the decomposition of waste in Seattle [13]. On average, a building usually lasts only about 50-65 years [15], so if developers could find ways to make buildings last longer, these emissions from demolition would decrease significantly.

In addition to the lack of GHG emissions from its production, wood is also a better insulator than concrete and steel. Thus, over the building's lifespan, it will require less energy to heat the space. Wood can also be prefabricated off-site, which speeds up the construction process and, in doing so, decreases the carbon footprint of the building. Wood is also much lighter than concrete and steel, meaning less labor is required during construction, thus lowering overall costs of the building. The amount of material used to construct buildings will also decrease, further reducing emissions and costs. Additionally, wood is plentiful and renewable, so it tends to be cheaper than steel and concrete [16]. Cross-laminated timber is a type of mass timber with an average cost of around $50 per square foot, which is about $14 per square foot less than concrete or steel [17].

In addition to wood's financial and environmental benefits, wood is more appealing to people — they tend to like working with and in wood buildings better than in buildings made of other materials [18]. Starting with the construction of the building, in multiple studies conducted, the construction workers interviewed about their preference of material to work with liked wood better because it was easier to handle due to its weight. Numerous studies have also stated that people working within wooden buildings tend to have a better experience in their workplace due to the warm and natural appearance of wood. A total collapse of a building due to fire is also less likely since the combustion of wood is more predictable, and mass timber can uphold the structure for a greater amount of time under extreme heat, unlike untreated steel, which could melt within an hour [19].

However, there are some downsides to building with wood. According to an article discussing the stakeholders of wood construction, many architects and engineers are not taught in school how to build with wood, as most of their education is structured around concrete as the primary building material, so it can be challenging to find people with education in wood construction. Another factor is that it is hard to source enough wood from one location, which adds inconsistency to the quality. Therefore, much of the wood gets wasted. However, despite these few issues, wood can have a positive impact overall if used correctly [20].

Another and newer alternative to conventional concrete is more sustainably-produced cement, since cement is the main factor in concrete's high carbon emissions. There are many ways to do this, but companies involved are primarily focused on finding the most cost-friendly alternative. One way is to simply make the concrete last longer once used in the building. This would decrease the demand for concrete production and its associated, decreasing emissions since less concrete would be produced. Another and more viable possibility to reduce the emissions associated with concrete would be to cut down the transportation-based emissions of concrete by using electric vehicles. Another possibility is to decrease the use of cement in concrete and find alternatives such as slag sand or stone powders, both of which produce fewer carbon emissions, but still maintain the strength and durability required for concrete [21]. Crushed-up and recycled old concrete could also be used as an alternative additive. This would divert used material from landfills and decrease the GHG emissions produced during the manufacturing of cement. Furthermore, manufacturers could inject recycled carbon dioxide into concrete as it is mixed. A chemical reaction then occurs where the CO_2 converts to calcium carbonate, which improves the compressive strength of concrete. Because it enhances the strength, less cement is needed for the concrete. However, and most importantly, concrete manufacturers need to re-think where they are acquiring their energy from, and they must begin to transition to renewable energy sources due to the large amount of energy required to produce concrete.

Although decarbonizing concrete would dramatically reduce global GHG emissions, there are significant issues that must be addressed before the practice becomes widely accepted. For one, the upfront cost of low-carbon concrete is much higher than that of traditional concrete. This alone causes many companies to look past using green concrete. Unlike other green technologies, there is little government support for using alternatives to conventional concrete because of the safety problems regarding durability accompanying sustainable concrete. Because it is a new technology, there needs to be more research on using low-carbon concrete in practice and whether or not it is as structurally safe as traditional concrete. In addition, it must be produced in the same quantities as its counterpart, which would be extremely difficult to achieve. Also, companies must figure out how to make concrete that is as long-lasting as standard concrete, since it must last up to 50 years or longer. If this technology becomes more readily available, widespread, and developed, it could become a promising material for construction in the future.

Steel is another material in the construction process that must be improved to become less impactful on the environment. The steel industry produces 7% of global emissions, more than any other heavy metal industry [22]. It is also the most commonly used metal in the world today, so a transition to low-carbon steel would be incredibly difficult [23]. The demand for steel is predicted to continue to increase, so we must start looking for ways to decarbonize the process.

The production of steel is so harmful to the environment because most steel is manufactured in coal-fire blast furnaces, which creates huge amounts of carbon emissions and requires a lot of energy. Similar to the transition to sustainable concrete, the transition to green steel must require these furnaces to be fueled by renewable energy. Additionally, since steel can be forever reusable, steel recycling is another way to decarbonize the industry. Another extremely promising alternative is using green hydrogen as a power source for steel production.

Green hydrogen is hydrogen produced from water through a process known as electrolysis. If electrolysis is powered by zero-carbon energy, then the hydrogen creation process is extremely low-carbon. Figure 5 illustrates this process. Additionally, when hydrogen is burned to create the electricity needed for the factory, it only emits water and nitrogen oxides which can be less harmful with management. In an article by Leigh Collins, they discuss how hydrogen is also incredibly easy to store and readily available worldwide. Green hydrogen is likely to become the cheapest way to produce steel in the U.S. in the near future due to President Biden's Inflation Reduction Act. The act will offer a subsidy of up to $3/kg for green hydrogen production, which could reduce the original price of about $3.35/kg to just $0.35/kg, which can support cheaper steel production. This subsidy will become active in the United States in 2024. However, China and India produce most of the world's steel, so this would not drastically decrease the emissions from steel production as hoped. China, however, is on a path where low-carbon steel made with green hydrogen will become cheaper than traditional steel by about 2040. The European Union is also implementing a tax on imports depending on their carbon intensity. As a result, if the American steel industry becomes greener, it will increase steel production, due to demand for low-carbon imports from the European Union. Therefore, China and India will also be further incentivized to switch to more sustainable steel production. Globally, renewable energy and green hydrogen prices are dropping, so sustainable steel production could become cost-competitive or even cheaper than coal-based steel production over time with government support and incentives [24]. Thus, low-CO_2 steel made with all these techniques discussed, specifically green-hydrogen, will likely become a widely used technology in the upcoming years.

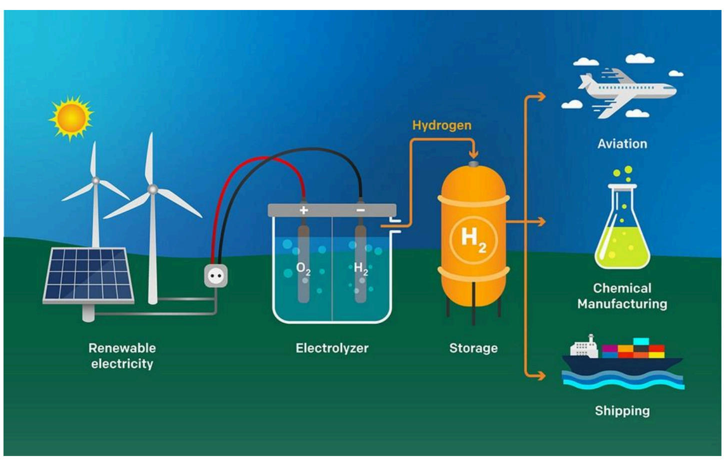

Figure 5: Green hydrogen production with renewable electricity [25].

Although materials used during construction to build the buildings are extremely important to their overall sustainability, there are many factors that affect the building's emissions. This can include heating, lighting, and electricity efficiency. Once a building is built, most of its emissions will come from burning fossil fuels to produce heat and electricity for light bulbs, computers, outlets, and other necessary appliances. In Seattle, most emissions come from burning natural gas for heating purposes. Luckily, many alternatives to conventional HVAC systems are low-carbon and extremely energy efficient. These include heat pumps, radiant cooling and heating, and heat recovery systems. Although these are just a few options, there are numerous ways to decrease heat use, such as not opening windows, strategically placing windows to allow or prevent heat from entering, and using curtains. These are less expensive solutions that most people can use daily.

Heat pumps use electricity to transfer heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. During warm months, the heat pump will absorb cool air from the outside and use it to heat the building, and when it is colder outside, it will absorb the heat from the air to heat the space. See Figure 6 for a visual image of how this works. A heat pump works in all climates, and there are three different types depending on the building's needs. The three different types are air-to-air pump, water-to-air source, and geothermal. The most common type is the air-to-air pump, which can reduce electricity use from heating by about 65% [26]. However, geothermal heat pumps offer higher efficiencies of up to 70-80% less than a typical heating system, but they do cost more to install [26]. Once the system is installed, the operating costs are lower because the ground temperatures stay more constant than air temperatures [26]. This is the same with water-based heat pumps.

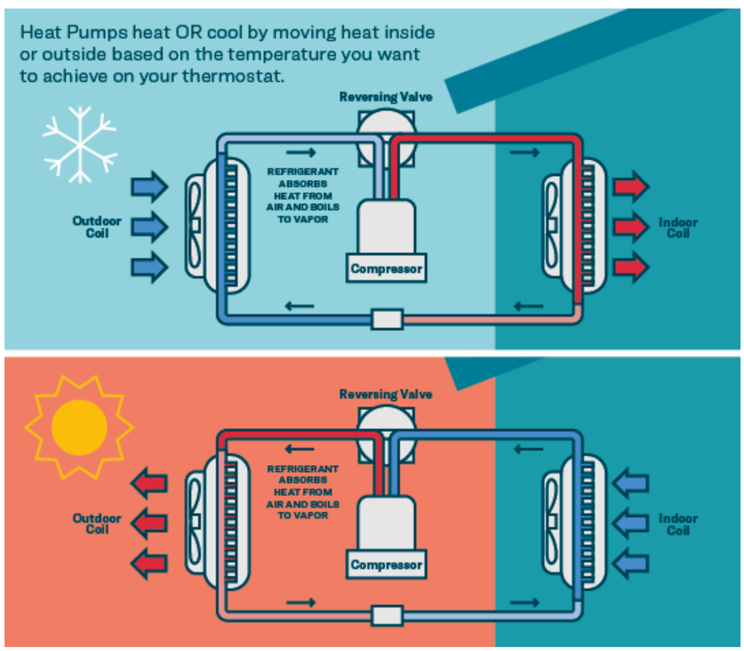

Figure 6: How a heat pump works in cold and hot weather [27].

Heat pumps do not require ducts, so they are usually simpler to install. The system also includes both heating and cooling features, thus the building would not require two different heating systems. Additionally, heat pumps do not use combustion in order to heat the building, and there are no carbon monoxide risks, so the system is safer overall [27]. Although the upfront cost is much higher than that of a traditional heating system, the utility bills will be lower because heat pumps do not require heating fuels, and the price of electricity will be cheaper due to the higher efficiency of a heat pump [27]. President Biden's IRA will also offer tax credits and incentives for the installation of heat pumps, and the incentive will reach up to $8,000 [28]. The main downside is that the heat pumps require service twice a year to change the filters. They also only last 10-15 years, and heat pumps tend to lose efficiency once their age hits double digits [29]. Conventional heating systems usually last longer by about 5-10 years. However, companies are starting to develop upgraded heat pumps that will last longer, but these will be more expensive upfront. These systems are a great option if looking for low-carbon and higher-efficiency heating technologies, but they require much more maintenance and will not last as long. It is also important to note that these systems only produce low carbon if the electricity comes from a renewable source. This would be the case in Seattle, so heat pumps would be a great sustainable option for alternative heating systems.

As each unique building has different needs, there are also many different sustainable heating techniques. Another option is radiant heating and cooling. Radiant heating systems supply heat directly to a building's floors or ceilings. Heating tubes are typically installed under the floor or ceiling panels to deliver heat. Radiant cooling works by absorbing heat radiated by the rest of the room. Systems similar to this concept have been in use for a very long time. Ancient Roman bath houses built fire chambers under the floors or in walls to heat buildings [30]. More recently, Lloyd Wright started to adopt modern radiant heating into his designs of buildings in the early 20th century [31].

As with heat pumps, there are multiple types of radiant heating. The least common is air-heated radiant floors. This type of heating uses ductwork installed beneath the floor that has hot air passing through the duct. As the hot air passes through, concrete between the ducts and the flooring conducts the heat, and the heat rises through the whole room to heat it, which Figure 7 demonstrates. Since this technology requires ductwork, it is much less cost-effective than the other types of radiant heating [32]. An alternative is electric radiant floors that use a grid of electric wires beneath the flooring. This technique requires flooring with a wide surface area and a material with strong heat transfer, such as ceramic tile. Electric radiant floors are most commonly found in smaller spaces such as bathrooms and are not usually the direct heater of the room. This type of radiant heating is best for existing buildings undergoing renovation since the installation is relatively simple and quick. The last type of radiant heating is hydronic radiant floors, which use a grid of tubes that contain water instead of air like the air-heated radiant floors (see Figure 8). The water is warmed by a boiler or water heater, passed through the tubes, and is used to heat the whole space. This system can be used for the whole building since the temperature can be controlled separately from room to room, and it is compatible with a wide range of flooring materials. Hydronic radiant floors are difficult to install during a renovation, so they are mostly used when the building is being newly constructed.

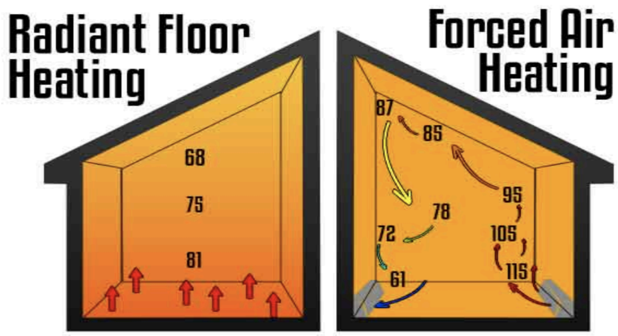

Figure 7: Diagram of radiant floor vs. traditional heating system [33]

Figure 8: Image of an installed hydronic radiant heating system[6].

Unlike typical heating systems, radiant heating tends to be more comfortable in buildings because it does not produce any noise or air pollution. In addition, buildings using radiant heating are 90% more energy efficient in terms of heating than buildings not using radiant heating [34]. Again, assuming the electricity comes from a renewable source, this is a great low-carbon heating system that will lower utility costs. Radiant heating is also very compatible with heat pumps, so if the radiant heating system is not heating the building to a certain temperature, a heat pump can be installed. Lastly, the system will last about 20 years, but yearly maintenance is required [33]. However, as with all heating systems, there are downsides to radiant heating. This system has a high upfront cost depending on the location and size of the project. Radiant cooling is also relatively new to North America, so it may be difficult to find companies installing it. The buildings must have a specific type of flooring that will conduct the heat rather than insulate it. Tile flooring is the best type of flooring for this and the most common. There is also a time lag for the heat, so the floors have the potential to become extremely hot. Additionally, buildings with large rooms and high ceilings would have more difficulty heating the whole room and may require supplemental heating, such as heat pumps. Overall, this system is more useful in smaller buildings and homes but is still useful as a supplemental heating technique.

The last heating alternative to be discussed is heat recovery systems. Heat recovery systems are normally located in an attic or a roof space. The system heats the rooms by extracting heat from the air in the rooms and passing it to the air that comes from the outside (see Figure 9). Its efficiency is a result of recycling heat from the air that occurs in the heat recovery system. With this, the heat recovery system creates an airtight environment but prevents the common problems associated with this, such as asthma, condensation, mold, and other irritants. Instead, the heat recovery system extracts the moist and stale air from each room and replaces it with fresh air. Additionally, heat recovery systems can save up to 30% on energy bills due to its efficiency [35].

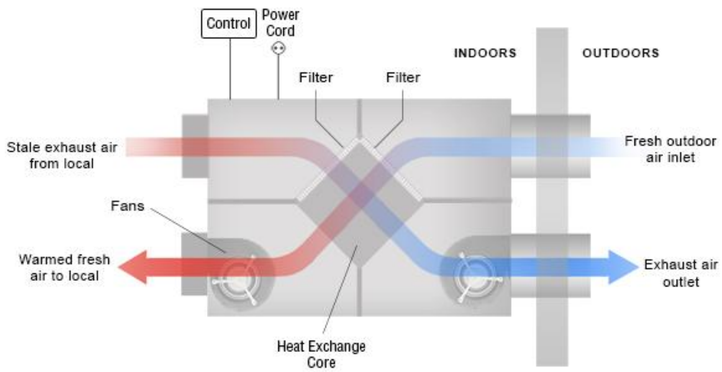

Figure 9: Diagram of a heat recovery system [36].

Although heat recovery systems have some benefits, the negatives arguably outweigh the positives, considering the more energy-efficient options on the market. The first uses of this technology date back only to the 1970s, so there has not been as much development and research on improving this system as with other heating alternatives. The second downside is its cost. The cost of installing the system is extremely high because the heat recovery system must be connected to every room with ducts so warm air can be pumped through the building. It is also extremely difficult to install, especially in older buildings that are undergoing renovation; this can increase both the cost and duration of installation [37]. There must also be regular maintenance because failure to perform check ups will result in reduced efficiency and possible health problems due to possible mold build-ups or contamination of other harmful substances. Heat recovery systems are also designed to operate continuously, so they are unsuitable for buildings with irregular occupancy patterns. Due to the recent pandemic, it is becoming increasingly common to have hybrid working systems or fully remote environments, so it is also becoming less common to have regular occupancy patterns within a building. Additionally, the system will only last 10-15 years, less than a typical heating technology [38]. However, the cost of a heat recovery system has been decreasing over the years due to improved technology, so it is possible that this will become a viable option in the future.

With all these advancements in the materials and technology that are involved in a building, many of them are still not being used regularly, mostly due to cost and availability.

However, some buildings have accomplished amazing sustainability goals by today's standards. Although these buildings are praised for their green efforts, the world must reach a point where these accomplishments are the norm. Cities worldwide are starting to build extremely sustainable buildings to draw media attention to the area and set the standard for other buildings. A few large and smaller projects have reached these sustainable standards in Seattle. Most notably, the previously mentioned Bullitt Center is world-renowned for being one of the greenest commercial buildings in the world [39]. The building has many impressive features, including its 250-year lifespan, which decreases the average annual GHG emissions. The Bullitt Center was also built without any red-list building materials, which contain chemicals identified as harmful to humans, animals, or the natural environment. This step was necessary to have the title of a “Living Building”. Additionally, the building does not use any extra water, as it has an efficient rainwater collection system that is special to Seattle because of the city’s especially rainy climate. In order to heat the building, the center uses ground source heat exchange, radiant heating and cooling, and a heat recovery system. These systems and the building's electricity are powered by 100% on-site renewable energy [39]. In order to decrease energy usage and reach the 100% on-site renewable energy standard, the building's energy efficiency is 77% better than that of the average Seattle office building. To see a more in-depth image of how they accomplished constructing a Living building, see Figure 10.

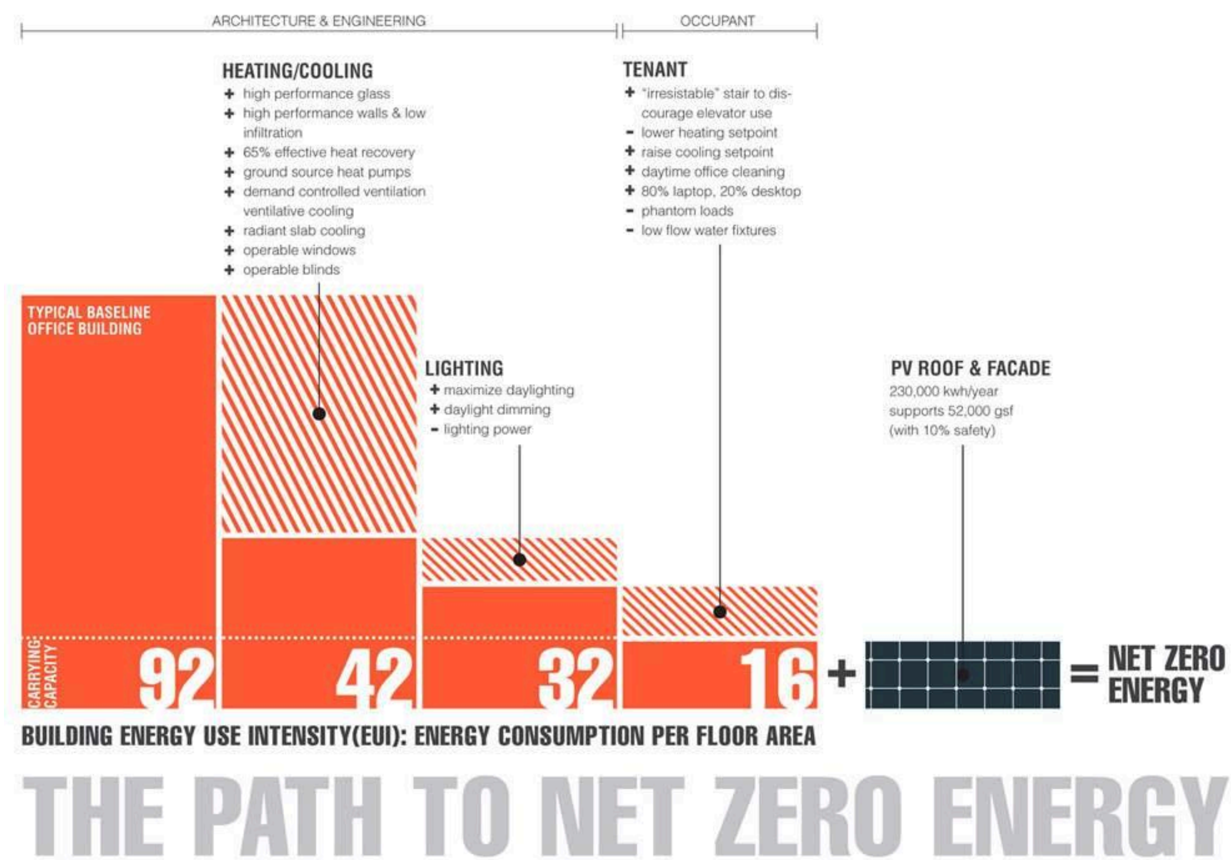

Figure 10: The Bullitt Center's strategies for reaching net zero energy [39].

A second building in Seattle that is notable for its sustainability is the Climate Pledge Arena, which is impressive due to its footprint and seating capacity. The Climate Pledge Arena was opened in October of 2021 and has since held games for Seattle's WNBA team, the Seattle Storm, and their NHL team, the Kraken, along with many different events including concerts. The arena can hold over 18,000 guests while still remaining among some of the most sustainable buildings in Seattle [40]. The website for the arena goes into detail about how they reached this level of sustainability that has been difficult for many other buildings to reach. The building is silver-tier LEED-certified and sends zero waste to landfills. The arena diverts 90% of waste generated on-site from a landfill by having only compostable or recyclable materials within the arena available for purchase. They also have an on-site sorting team that sorts waste during and after events held in the stadium. In addition, they work with specialized recycling plants to recycle materials that cannot go through normal disposal systems and upcycle or donate any materials they cannot recycle [41].

The arena is also powered by 100% renewable energy and strives to reach net zero carbon emissions by 2040. The stadium uses onsite renewable energy through solar panels installed on parts of the roof and parking garages. However, the whole roof of the stadium cannot be utilized for solar electricity generation because parts of the roof have been nationally registered as a historic landmark, thus preventing the installation of solar panels on most of the roof. Therefore, the electricity that is not generated on-site comes from other, possibly non-renewable sources. In order to combat this, the arena purchases a Renewable Energy Certificate (REC), which is one megawatt-hour of electricity generated from a renewable energy resource and delivered to the energy grid. During the construction process, the contractor also attempted to lower their emissions as much as possible by offsetting the emissions from the building process. They did this by purchasing and retiring 37,838 metric tons of carbon from the atmosphere. Although very beneficial to the environment, this process was extremely expensive and unrealistic for most buildings. In addition to lowering carbon emissions from the stadium itself, the arena has implemented more strategies to lower greenhouse gas emissions in Seattle. Climate Pledge is one of the only arenas in the country that offers free public transportation to games and publicly encourages people to take a more sustainable mode of transportation to arrive at the arena. Furthermore, the arena contains many vegan and vegetarian food options, which encourage consuming less meat, essential to lowering carbon emissions globally. Overall, the arena has raised the standards for new stadiums and arenas being constructed today and has proved that sustainable construction practices are achievable on the largest scales [41].

Ultimately, constructing green buildings starting now, as we have seen with Climate Pledge Arena and the Bullitt Center, rather than continuing with current construction norms will prevent large additions of carbon to the atmosphere in the future, which will be inevitable if we do not take the necessary steps. The construction industry already has many resources and options available to reach this goal, such as the technologies discussed thus far. In order to reduce embodied GHG emissions, the construction industry must reduce its environmental footprint while constructing buildings. This can be achieved by using wood as an alternative to concrete or steel, decarbonizing concrete via various techniques, or decarbonizing steel using green hydrogen as its power source. The built environment must also focus on its operating emissions to decrease its effect on the global climate. This can also be achieved in many ways, such as using heat pumps, radiant heating, or heat recovery systems to heat the building. However, new upgrades can be paired with these solutions to create even more sustainable buildings. Some examples of additional upgrades include using hemp for insulation and green roofs, which may be painted white so they reflect heat or have plants that will cool the building as well. All of these solutions will also decrease the energy needed for heating. Furthermore, technology for heating and lighting systems is continuously improving their efficiency. It is also important that each building operates on clean electricity and energy from renewable or low-carbon sources such as nuclear energy. Using these additional upgrades, paired with the technologies already discussed in depth, will be necessary to reach the net zero emissions goal many countries hope to achieve before 2050.

When considering further sustainability improvements to buildings, it is important to note seismic, aesthetic, and economic factors among others. Using Seattle as a specific example, while this city has great potential to decarbonize buildings, we also see the difficulties of going from concept to reality. In Seattle, specifically, buildings must be constructed to be earthquake-resistant, as the area is due for an earthquake of large magnitude. In addition, any building materials must be waterproof and not rot or rust under rainy conditions. These conditions may make finding environmentally friendly solutions more difficult. Certain types of wood may not be a viable option in Seattle due to its rotting traits. Most of all, the solutions discussed thus far must become economically competitive with their traditional counterparts, or else creating mass-spread green buildings is virtually impossible. But, with improving technology and government incentives, it is becoming increasingly likely that we will have a future full of low-carbon buildings.

Although large companies and governments involved in the construction process are mostly responsible for lowering environmental impact through reducing waste and GHG emissions during the building's lifestyle, consumers and people working inside of the building can help to encourage these practices and help to further lower the impact buildings have on the environment. Employees can request improvements to a building from their employers, and homeowners can switch their appliances for more environmentally friendly alternatives. Additionally, people who own commercial or residential buildings, architects, engineers, and general contractors all have an influence on making more sustainable choices for their buildings. Ultimately, everyone has a role in this necessary change in construction practices. In order to achieve a greener future, everybody must commit to their role and either continue or start their transition to greener, more sustainable practices in construction and operating buildings.

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