Environmental Dimensions of Climate Change: Endurance and Change in Material Culture

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Background

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In her seminal 1962 book the *Silent Spring* [1], Rachel Carson declared, “at times, technological progress is so fundamentally at odds with natural processes that it must be curtailed.” She wrote: “Man’s attitude toward nature is today critically important simply because we have now acquired a fateful power to alter and destroy nature. But man is a part of nature, and his war against nature is inevitably a war against himself?” Carson’s activism inspired the environmental movement that led to the creation of the US Environmental Protection Agency in 1970 (EPA).

For many, “man’s war against nature” began with the industrial revolution that has since brought much progress and prosperity to industrialized nations but comes as a threat to man’s existence in the form of critical worldwide climate change. The 2015 Paris Agreement [2] is the international treaty on climate change that has set a goal of keeping global warming to less than 2 °C (preferably 1.5 °C) compared to preindustrial levels. This is the goal that 193 parties agreed to accomplish by 2050 by each proposing a Nationally Determined Contribution (NDC) and a path to reach it.

In its Executive Summary, the McKinsey Global Institute [3] stated that “As of December 2021, more than 70 countries accounting for more than 80% of global CO_2 emissions and about 90% of global GDP have put net-zero commitments in place, as have more than 5000 companies, as part of the United Nations’ Race to Zero campaign.” This underscores the importance of collective and immediate global action to confront climate change.

A framework to measure environmental impact is known as the I = f (P, AT), created by Paul Ehrlich and John Holdren in 1971 [4]. It concludes that “there are three main factors affecting environmental impact: (1) Population (P), (2) Affluence Level (A), and (3) Technology,” and as all these continue to rise and develop, so will their collective impact (I). These three factors contribute to urbanization rates, which are also on the rise. The United Nations projection is that by 2050, two-thirds of the world’s population will live in urban areas. The surge in construction projects to meet this demand is why net-zero buildings are more relevant [5]. The projected growth will require increased infrastructure and the construction necessary to absorb the additional 2.3 billion urban migrants. This underscores the gravity of trending urban development and the dramatic increase in carbon emissions that it will undoubtedly entail, in addition to impacting land use, air and water pollution, resource shortages, the heat island effect, and the resulting exponential increase in energy consumption.

It is now widely accepted more than ever before that it is imperative to lower carbon emissions to avert a major climate calamity. It is evident that there is no silver bullet or a single solution to the environmental crisis. Global cooperation is essential to solve this global quandary. Everyone has a role to play in the fight against climate change, but there is only so much we can do as average citizens. On the other hand, the building sector can have a much greater impact [6]. According to the US Department of Energy (DOE), buildings are responsible for 38% of all energy-related greenhouse gas (GHG) emissions each year. This is a considerable percentage, and by targeting the building sector specifically, significant progress could be made in the global effort to reduce carbon emissions. The Paris Agreement calls for the building sector to reduce the primary GHG emissions by 50% by 2030 and net-zero by 2050 [7].

This goal may seem lofty, but countries like the UK demonstrate that it is possible. The UK was the first to sign "a legally binding target to achieve net-zero carbon emissions by 2050." The ARUP Group, located in London, England, conducts research and provides detailed reports to be used as a framework to empower building sectors and other countries to strive for their net-zero aspirations. The authors of the ARUP publication titled *Net-zero Carbon Buildings: Three steps to take now* report [8] that they saw surprisingly widespread and fast action in the property sector. "Twenty-three leading property organizations signed a climate change commitment agreeing to set a pathway to net-zero carbon for their organizations." Others in the UK have also joined this movement and have begun implementing changes to achieve this goal, which, until recently, was something that seemed impossible. In another publication, the ARUP Group further promotes using building incentives, conducting complete lifecycle analyses, and defining a clear net-zero energy definition to move the property sector toward reaching the goal of carbon neutrality and net-zero buildings. They believe that achieving net-zero carbon for buildings is possible for both existing and new buildings, but to achieve this goal, new approaches must be taken for buildings of all types and scales [9].

This type of large-scale change will not happen overnight, and it is important to understand how to "encourage organizations to continue on the journey to achieving net-zero." One way to do this is through incentives and short-term recognition for progress. It is important to communicate the importance and value of making these changes with companies because "improving emissions can be a costly project and will often see its biggest returns in the long term. Therefore, short-term recognition can be the added boost that many companies need to push them to engage fully with greener practices."

The Leadership in Energy and Environmental Design (LEED) is an example of one of these recognitions that constitute an "international verification of a building's green features." [5] The Building Research Establishment Environmental Assessment Method (BREEAM) is another leading sustainability assessment for buildings and infrastructure. These incentives and the organizations they represent also participate in research and create the industry standards that the ARUP Group calls for.

These are just two of the main recognition certifications already in place that can distinguish built projects and serve as the motivation a company needs to make greener choices that lower its carbon emissions [5]. Along with these incentives, certain cities lead the way in getting sustainable accredited buildings by making cities broad goals and requirements for new construction. To lay out some of the leading states' approaches and targets, Boston was ranked the number one energy-efficient city in the country as of 2013–2019. A few of the city's targets are to be carbon neutral by 2050 and that every new building must meet the minimum requirements of the US Green Building Council (USGBC) and be LEED-certified. Many other states also make great strides toward creating a greener future, and these show the importance of policy-making in a city toward incentivizing and requiring greener building practices.

Another way to reach similar outcomes has been observed in Australia, where there has been a clear link between operational energy/carbon performance and overall value. There, an energy rating scheme called the National Australian Built Environment Rating System (NABERS) is “credited with halving the average energy intensity of commercial property.” This change has happened because the majority of “commercial properties that have a high NABERS rating in Australia benefit from a value premium of approximately 20%.” [8] Linking lower carbon emissions to a direct monetary value has resulted in greater industry participation. The UK has just launched a similar rating scheme. While these types of efforts are making significant changes, they mainly address operational emissions. Currently, there is no framework that effectively links “embodied carbon and asset value,” which is needed “if we are to empower the market to move toward true net-zero.” This example illustrates that “transformation is driven by incentives,” and having accreditations that “define clear markers” and clear benefits will produce results.

While these are promising examples, there is still much more to be done. Two-thirds of countries do not even have building codes let alone incentives to reach net-zero carbon emissions. This means that in 2019, approximately 55 billion square feet of building area were constructed without energy standards. This is really important because, as stated earlier, the world’s overall population is growing exponentially, and 90% of urban growth is concentrated in countries in Africa and Asia. Calculating an individual country’s carbon impacts can get tricky, but the main point is that there needs to be regulations put in place to ensure that new construction is bringing us closer to net-zero rather than farther from it.

Globally and across all sectors of the economic and political spectra, there needs to be a multifaceted, gradual yet deliberate, and orderly transition to reducing carbon emissions to meet the goals of the Paris Agreement by 2050. In the industrial manufacture of building products and components, Life Cycle Analysis (LCA), Design for Disassembly (DfD), component reuse, and other parameters and benchmarks all need to be mandated to slow down global warming to an acceptable level compared to preindustrial standards. In the construction and operation of buildings, decarbonization through the use of clean energy and sustainable alternatives will collectively reduce emissions by appreciable margins.

Definitions

Net zero refers to the state of overall equilibrium between GHG emissions into and removal from the atmosphere. Although the concept is simple and the objective is righteous, many believe that the net-zero equation has not yet been solved. Not unlike a *steady state* condition in thermodynamics, net zero involves many sources of emissions (carbonization) and unequal sources of negative emissions (decarbonization) that need to be balanced.

The following definitions are from the 2020 McKinsey Article: Data to the rescue: Embodied carbon in buildings and the urgency of now.

> **Embodied carbon** consists of ALL the GHG emissions associated with building construction, including those that arise from extracting, transporting, manufacturing, and installing building materials on-site, as well as the operational and end-of-life emissions associated with those materials. [10]

> **Cradle to gate** embodied carbon refers to the emissions associated with only the production of building materials, from raw material extraction to the manufacturing of finished products; it can be thought of as supply-chain carbon, and it accounts for the vast majority of a building's total embodied carbon. [10]

Operational Carbon, on the other hand, is what ensures user comfort in a building and includes carbon emissions from building operation and maintenance such as heating, cooling, ventilation, lighting, power, etc.

Design Decisions Based on Embodied Versus Operational Carbon

> Buildings are currently responsible for 39% of global energy-related carbon emissions: 28% from operational emissions, from the energy needed to heat, cool and power them, and the remaining 11% from materials and construction. [11]

The International Building Code (IBC) has required a 50% decrease in energy use in *new buildings* since it was first adopted in the USA in 2000. This has led to significant reductions in operational carbon emissions but not in embodied carbon emissions. Also, the IBC does not require upgrading energy efficiency for *existing buildings* unless they are scheduled for "substantial" renovations.

In contrast to operational carbon, embodied carbon is finite rather than perpetual, can only be reduced in the initial building design and construction stages, and cannot be removed from existing buildings. A large part of a building's embodied carbon emissions lies in the choice of building materials and components. In general, carbon emissions can be reduced firstly by choosing locally sourced materials that will require nearer transportation and secondly by choosing products with longer life spans that will not require frequent replacement.

To reach net zero, it is critical that building design and construction follow a sequential approach to critical decision-making from the inception and at every stage of development and implementation. The greatest impact on a building's carbon emission trajectory begins in the earliest design phases. Fundamental decisions regarding massing, ceiling heights, facade designs, and passive design strategies all impact a building's full carbon lifecycle. Implementing efficient systems, using on-site renewable energy, minimizing waste by reusing materials, and choosing products manufactured nearby are all to be considered early on in a designer's efforts to mitigate carbon emissions. By taking a whole life-cycle approach, tradeoffs will be more accurately considered at every stage of a project [8].

While this is all crucial to reaching net-zero, it is only really "delivered in operation." One of the major hindrances to buildings reaching their carbon goals is the enduring conflict between "building occupants and their operational expectations." To have a building reach net zero, there will inevitably be greater restrictions on energy use, which will impact the occupants who may not be used to limiting their energy use. This disconnect can be represented through the distinction between a net-zero-*enabled* building and a net-zero-*achieved* building. This means that a building may be enabled to become a net-zero building, but it is up to the occupants and its operational usage to achieve this goal. Reaching full net zero will require a method to measure energy usage, and one such format is known as the energy use intensity (EUI), which gives a building a floor-by-floor calculation of its energy usage and helps give a definite tracking system for energy usage. In addition to clearly understood markers, early involvement and collaboration from every stakeholder throughout the building's lifecycle are needed, along with cooperation and clarity of expectations with all involved to accomplish a net-zero full lifecycle building [8].

Whether it is a net-zero retrofit, or a new build, designing buildings to achieve net zero requires a fundamental change in approach. Design success has been measured by compliance outcomes but needs to shift to a focus on designing for operational performance and carbon reduction in every design decision. Demonstrating a strong link between value and performance will advance this data-driven approach vital to accomplish these changes. Some strategies to design with this approach include using advanced energy modeling systems, strategically locating apertures in the envelope to exploit natural ventilation, deploying the appropriate energy systems, and smart building controls that adapt to the occupancy of the building while minimizing energy waste. The benefits of each of these strategies need to be communicated so that these practices will become accessible and lead to widespread change in the industry.

In general, designing a building by following the "long life/loose fit" strategy will help ensure that new construction will stand the test of time. Having digital data on building materials thoroughly documented and readily available will help future designers learn how to best reuse and retrofit the buildings that are currently in use. After all of the design, decisions have been made, and the operational consumption has been addressed "to minimize a building's whole life carbon emissions, the final step to net-zero is to offset what's left." [8] The first steps will make the most impact, but investing in renewable energy is a positive step toward reaching net zero for the building industry and the rest of the world.

Many measures to reduce operational carbon emissions have been implemented across the USA and the world. These include replacing incandescent light bulbs with compact fluorescent bulbs since they last longer, produce less heat, and are generally more efficient. Zero emissions of clean energy from sources such as nuclear, wind, solar, hydro, geothermal, etc., are replacing energy generated from fossil fuels such as coal, oil, and gas. Although electric heat pumps are more expensive than traditional gas hot water boilers, they are more efficient and produce less CO_2 emissions as they run on clean energy instead of fossil fuels. Local jurisdictions in large cities are trying to reduce emissions in buildings in several ways. In New York City (NYC), there will be a ban on gas-powered stoves and water boilers for a new building under seven stories starting in 2023 and for taller new buildings beginning in 2027. This targets 6% CO_2 emissions that are traced back to residential gas heating and cooking [12]. Another example of NYC leading in sustainable development nationally and internationally by restricting operational carbon is the Local Law 97 (LL97) [13], which places caps on carbon emissions on larger residential and commercial properties in the city.

On average, the embodied carbon in a typical building is 50% in its structure, 30% in its envelope, and 20% in the interior [11]. The efforts to limit embodied carbon in buildings appear to be less stringent than those of operational carbon. For example, Architecture 2030 [14] has set voluntary targets for embodied carbon reductions; these are an immediate reduction of 40%, then 50–65% by 2030, and zero emissions from materials by 2040. Similarly, the SE2050 [15] is the commitment by the Structural Engineering Institute of the American Society of Civil Engineers to meet the transitional embodied carbon reductions that reach zero by 2050. There are many similar efforts in the UK, Europe, and Australia, and cities and countries across the world are drafting commitments to reduce carbon emissions in building materials.

Concrete is the second most used material on the planet after water [16]. It is, however, the greatest contributor to embodied carbon emissions because of the energy-intensive process of producing cement and other sources of emissions in the concrete industry as a whole. In addition to the energy-intensive process of burning limestone to make cement, there is also the extraction and transportation of fine and coarse aggregates. There are several strategies being deployed to improve concrete's environmental performance. These include carbon capture, in which CO_2 is injected into a concrete mix to sequester the carbon while providing additional strength and durability to a concrete mixture. Other strategies involve using Supplementary Cementitious Materials (SCMs) such as fly ash, slag cement, and silica fumes as a partial replacement for cement. There is self-consolidating concrete (SCC) which eliminates the need for vibrating the concrete mix in the formwork while reducing emissions. Photocatalytic concrete uses titanium oxide in the mix to keep the concrete clean while also healing any potential cracks.

This is in addition to many promising technologies that are in the research and development stage to scale up production to industrial levels. Graphene concrete, for example, has much greater compressive and flexural strength while also significantly improving the impermeability of the cured concrete, which implies that less volume of concrete and less reinforcing would be needed. Also, the stronger the concrete, the smaller and lighter the member, which would result in smaller support members and a resulting smaller foundation.

The carbon emissions from the production of steel are primarily attributed to the use of blast oxygen furnaces that burn fossil fuels. The making of steel from iron ore requires the use of this type of energy-intensive furnace. Significant reductions of emissions in the steel-making process are being realized through the use of electric arc furnaces, which are used to melt down steel and recycle it into other applications of the material. Steel does not lose any of its properties when it is recycled from a soup can or a car into a wide flange beam.

The Profound Impact of the Envelope Is Anything But Skin-Deep

One of the most impactful ways to reduce both the embodied and operational carbon levels in a building is by considering one of the most dominant systems of a building, namely, the building envelope. The facade design, building orientation, and envelope's mechanics are all integral parts of a building's carbon emissions and should be addressed in the following crucial strategies:

The first step to ensure the maximum utilization of natural resources is to purposefully study the placement and orientation of the building on the site. For example, harnessing the sun and providing access to natural light will reduce energy consumption while also reducing the demand for electrical lighting. Shading devices on the facade are also an important factor because they keep unnecessary heat out of the building so that less energy is used to keep it cool. Also, when considering the overall building massing and orientation, the phrase "long life loose fit" is often suggested [8]. This implies that design for the future with long-lasting and durable materials along with a loose fit may be adapted in the future to reduce the likelihood of premature demolition and the associated carbon release. Bolting steel members to each other, as an example of "loose fit," instead of welding them would produce less carbon release during the disassembly process.

The envelope should be designed or refurbished to ensure airtightness with good U-values. As mentioned earlier, currently, one of the highest potentials for energy savings is by achieving greater efficiency in heating and cooling loads. The facade has a direct link to the effectiveness of these systems based on their performance qualities. The Locker Group promotes its product as being able to help reduce a building's utility bills and the impact on the environment through its creative façade solutions [17]. With proper insulation, air-conditioned and heated air will stay in the building, and the lower energy consumption is attributed to leakage loss. Thermal readings can help identify areas where excessive thermal bridging exists in the facade that should be considered in new buildings and when updating existing buildings.

The common approach to designing a building to have a completely sealed facade with access only to artificial heating and cooling often results in dissatisfied occupants and higher energy consumption. One way the façade condition can be altered is to utilize hybrid passive strategies, including natural and mixed-mode ventilation. Movable components that allow occupants to access natural ventilation are a beneficial consideration in terms of both energy use and occupant satisfaction.

In addition to these overarching strategies, there are many specific technologies that have been designed to help support a net-zero building through the design of its facade. The climate emergency has motivated net-zero energy practices that have produced a wide range of new technologies. Among these are advanced glass window technologies that revolutionize energy efficiency in building facades. These include technologies that not only manage the energy transfer between the interior and exterior spaces but can also serve as a generator of power. The skin of a building is the foremost location to harvest solar energy. Photovoltaic panels are also among the new technologies available for use directly in the façade of a building. Harnessing solar power in the façade may facilitate reaching net-zero by providing a building with supplemental energy to offset operational demands.

There are a few avenues for upgrading the performance buildings that do not require complete demolition. Updating the facade is one of these. Companies like Pic Perf are suggesting a new facade to reach lower carbon footprints and net-zero emission rates because of the large impact the facade has on rendering a building net zero. A product like Pic Perf can make a building envelope more efficient by blocking the sun, improving wind resistance, and more [6]. Another way to upgrade the facade is through an insulation-retrofit, which will save energy and cut carbon in the long run, although it will increase the embodied carbon in the short run. This increase will be insignificant compared to the carbon impact of demolishing and rebuilding the structure. Retrofit measures extend the life of any building and will thus contribute significantly to reaching net-zero objectives.

An example of this type of retrofit is Triton Square in London [17]. Originally built in the 1990s, the redesign shows "what is possible through imaginative reuse, demounting, refurbishing and re-erecting the existing facade." The Arup Group took a marginal gains approach to this redesign and called it a revolution. "Team Triton chipped away at every aspect to save carbon, cut waste, and deliver the best working environment possible. Through a marginal gains approach, the team has refined and optimized dozens of systems, components, and strategies to deliver a highly sustainable building." This building was a huge success with 43% cost saving compared to typical commercial buildings, 40,000 tons of carbon saved, and 30% faster to completion versus a typical new build. Arup is leading the way in how we can approach new building projects to achieve net zero and particularly for retrofitting buildings. Updating existing facades with this type of strategy will be revolutionary in the building industry and the global efforts to reach net zero.

In this chapter, a comparison of different case studies is conducted with a focus on the facades and building envelope. In each case study, the façade was used anywhere between 6% and 21% of the whole life cycle carbon assessment. Comparative studies such as these are imperative in moving toward a net-zero future. Companies across the globe are calling for more data-driven, transparent approaches to creating clear targets that will help provide the framework needed to realize the net-zero carbon emissions goal by 2050.

Case Study: 888 Boylston Street

Architect: FXCollaborative

Introduction

Completed in 2016, FXCollaborative's 888 Boylston Street serves as a unique example of a cold climate high rise with a LEED Platinum certification. 888 Boylston Street is located in the city of Boston, MA, and was designed for the well-known sustainably interested Boston Properties, Inc. (BXP). While much of the attention given to this building is often centered around the energy generation of the design, this writing aims to examine a closer look at the envelope materials utilized and their contribution to the sustainable characteristics of the whole. While 888 Boylston Street does not set any records for its size or height, the building sets a precedent for the possibilities of sustainable buildings in the USA and serves as a model where educational tours on sustainable design are held. This writing primarily investigates the building's use of glazing as an envelope material and its relationship to the cold climate of the northeastern USA (Fig. 1).

Identified as a cold continental climate, Boston's weather includes warm summers and very cold and snowy winters. Boston is known to have a relatively unstable climate with alternating days of stormy and clear weather due to different air masses colliding from different directions [18]. Similar to Chicago, Boston's location along the water can result in relatively cool temperatures in summer due to cold current flows above the sea. Boston averages 47 inches of rain per year, 48 inches of snow per year, and slightly below the national average of sunny days per year [19]. The average temperature in Boston ranges from a high of 82 °F in summer to a low of 19 °F in winter [19]. As heating consumes more energy than any other building system in Boston's climate, passive techniques can and have been utilized to better provide thermal comfort indoors [20]. Air barriers and continuous thermal insulation are two of the techniques that can help mitigate thermal bridging. In some areas in Boston, water levels are also a concern. Many historical buildings contain elevated entryways to help combat possible flooding [21]. While many of the climatic characteristics of Boston can be combated with mechanical systems, these methods are not sustainable when compared to smart passive systems and other efficient sustainable strategies (Fig. 2).

Sustainable Features

888 Boylston Street is located among several other mid- and high-rise buildings near Boston's downtown and the Charles River Basin. The building stands as a mixed-use office and retail building at 17 stories high and includes an area of over

Fig. 1 888 Boylston Street. FXCollaborative Architects LLP

425,000 square feet [22]. In addition to the two floors of below-ground parking, the design includes 14 floors of office space and 3 floors of retail with additional varying occupancies scattered at alternate levels. Sustainable features of the building from the architect as illustrated in Fig. 3 are most notably recognized through the green roof, green terrace, energy-efficient lighting, chilled beam system, energy-generating wind turbines, sky gardens, rainwater-harvesting system, high-performance envelope, PV panels, bike storage, and elevated equipment [22]. Compared to traditional offices of similar size, the design consumes 47% less energy and 37% less water [23]. This results in an annual saving of $650,000 [24]. 888 Boylston Street serves as one of the highest-performing buildings in the

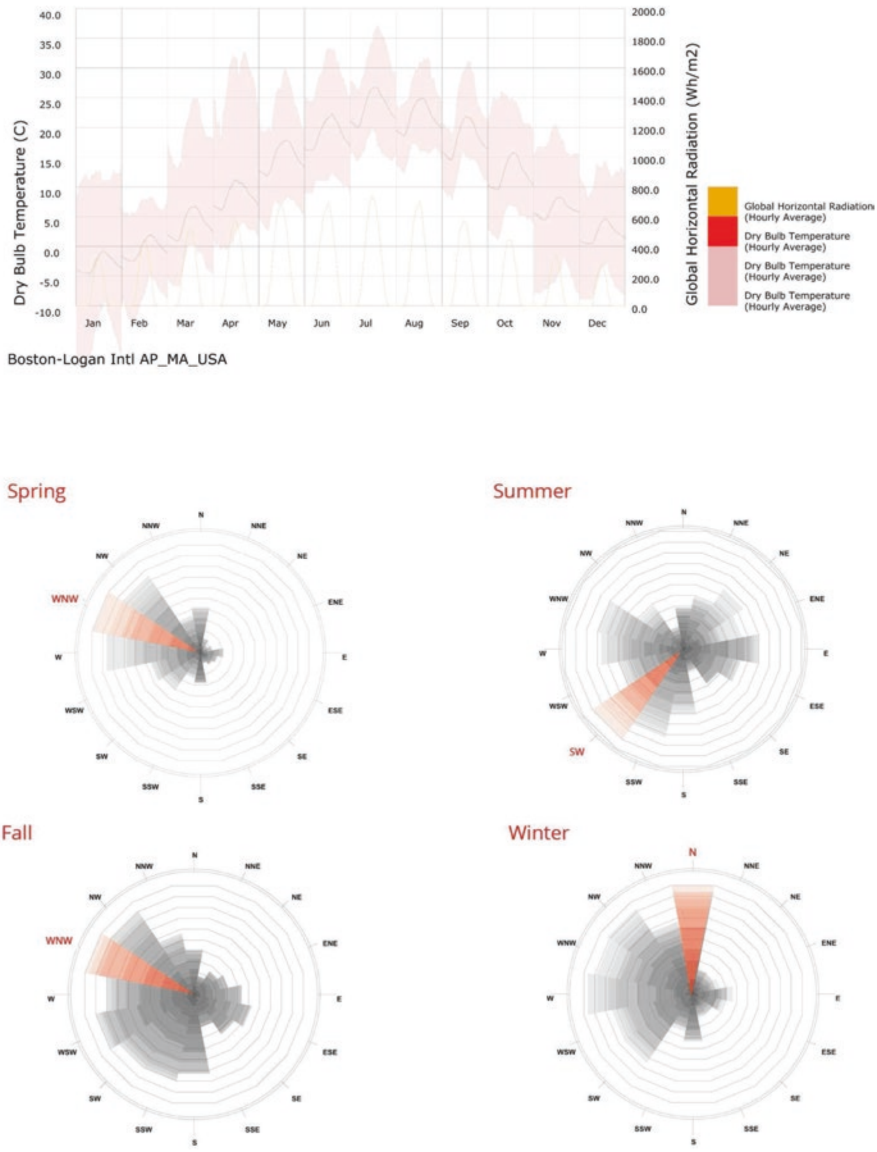

Fig. 2 Climatic data, dry-bulb temperature, wind roses, and psychrometric chart

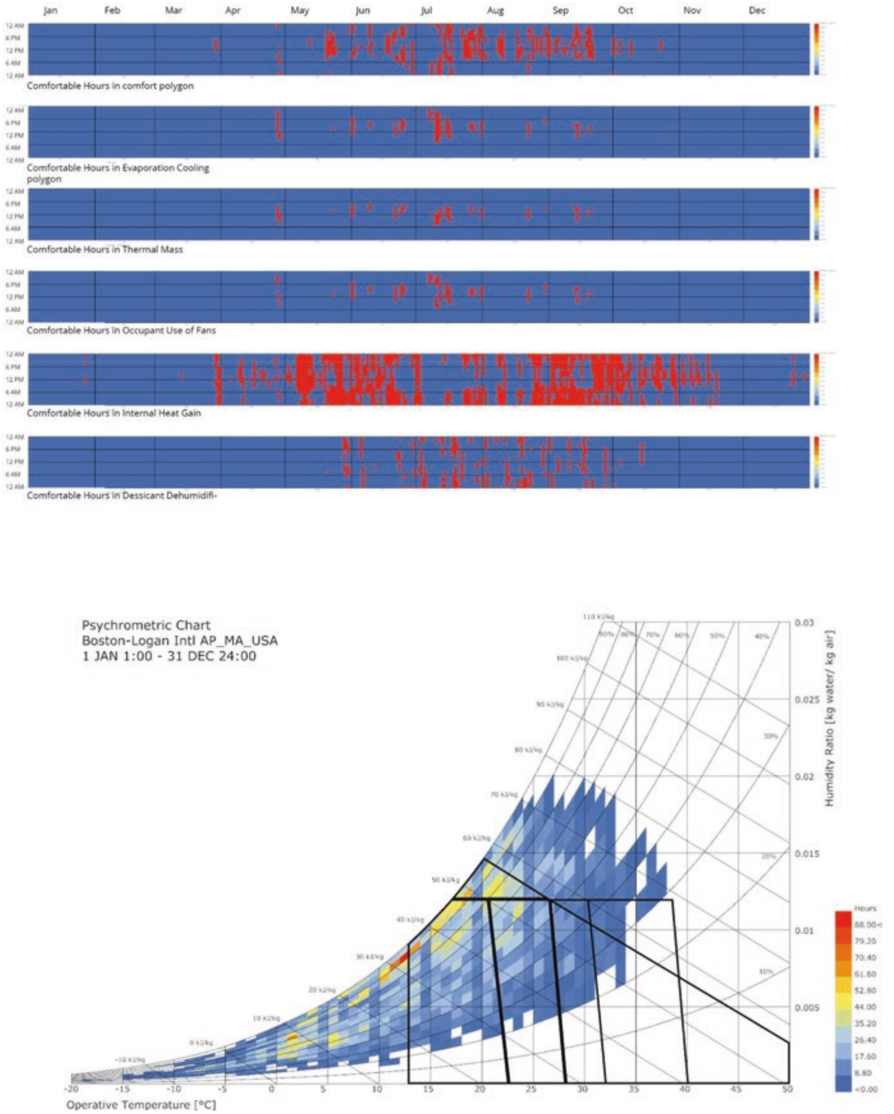

Fig. 2 (continued)

northeast and has the lowest EUI of any building in Boston at 40 kBTU per square foot [23].

The sustainable features in place at 888 Boylston Street reduce the energy use of the building by nearly 34.6% when compared to a traditional building of similar location and size [25]. One of the strategies in use that contributes to this amount is the rainwater-harvesting system. The rainwater-harvesting system, located on the

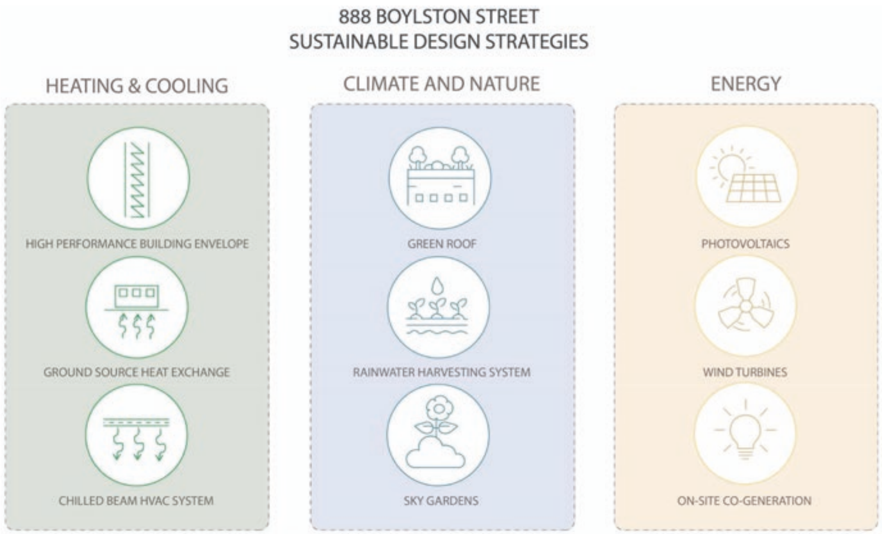

Fig. 3 Sustainable strategies. (Credit: https://www.usgbc.org/articles/boston-properties-pushes-boundaries-sustainable-design)

roof, utilizes collected water for cooling and irrigation. In the system in place, water is first stored in an underground tank where pollutants are removed. Nearly 20% of the total water used in the building is a result of the rainwater collection system [26]. In addition to water used in a chilled beam system for thermal comfort, the building efficiently utilizes a dedicated outdoor air system (DOAS). The system for air circulation uses only fresh outdoor air. Comparatively, a traditional HVAC system uses up to 75% stale recycled air. The DOAS system provides around 30% more fresh air and 50% more air changes per hour than a traditional HVAC system [24].

In addition to water and air, other natural elements such as light and plants are included in the sustainable design strategies in place. Biophilic elements, such as the rooftop garden and living walls, bring natural plant life to the building. The two common area walls display 13-feet-high green walls that provide connections with nature while in central Boston [25]. On the northern facade, 13′–6″ floor-to-ceiling heights provide vertical views to the outdoors. This viewing height, often called the "visual zone," is estimated to be 145% larger than most office buildings [26]. The structural design was even included in the daylighting to reduce the amount of columns that might intervene with natural light exposure.

Envelope

It is estimated that nearly 70% of the facade of 888 Boylston Street is comprised of glass. (Fig. 4) [25]. While this might not initially appear to be the most sustainable choice for daylighting and interior comfort, often requiring additional tools to control thermal comfort, the envelope of the design was analyzed extensively to

Fig. 4 Green roof. (Credit: FXCollaborative Architects LLP)

determine the most efficient system for the building's use. The chosen double-pane insulated glass reduces artificial lighting runtime in the building by nearly 60% to the baseline [27]. The glass itself is not entirely vertical. In this manner, the envelope system on the northern orientation curves upward to allow a larger quantity of light to enter the building's interior spaces (Fig. 5).

Operational Versus Embodied Energy

888 Boylston Street reaches a LEED Platinum status through both operational strategies in place as well as material choices that lower the total embodied energy of the structure. Operational energy is most notably seen through the visually present wind turbines and solar panels on the roof. However, additional mechanical and electrical systems in place help lower the operational energy requirements. Both the chilled beam system and DOAS help condition interior spaces without wasteful traditional HVAC techniques. Similarly, the building includes high-efficiency chillers that get rid of ozone-depleting chemicals and refrigerants [25].

The roof itself and subsequent wind turbines are visible from the exterior and not only contribute to the energy efficiency of the building but also provide a dynamic

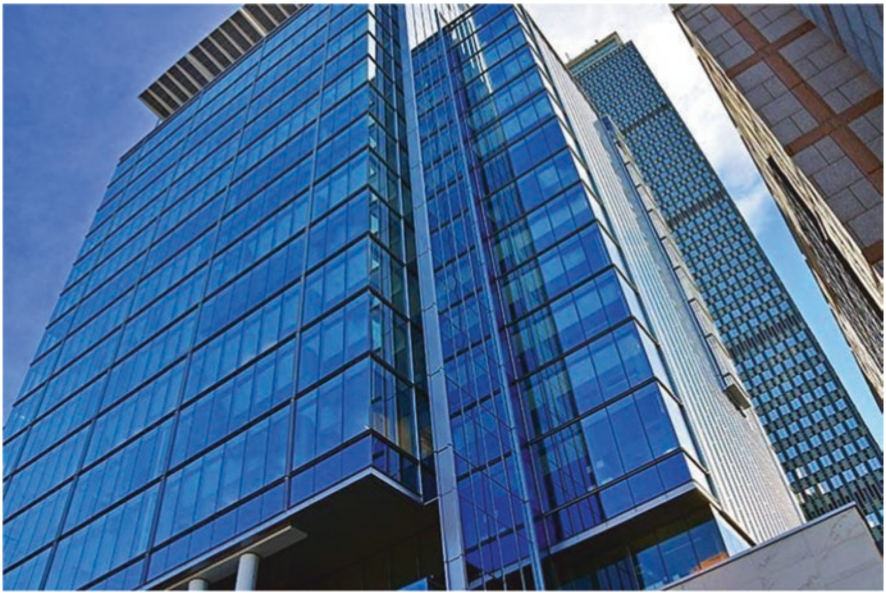

Fig. 5 Envelope. (Credit: AntyDiluvian)

crest of the building. The design includes 14 vertical axis wind turbines and a 134-kW photovoltaic (PV) system. As shown in Fig. 6, together, the roof system generates enough energy to run an estimated 15 homes in the state [28]. The roof system additionally includes garden areas and beehives. The beehives provide a safe home for the bees which in turn help pollinate the native plants on the rooftop. The plants themselves help to reduce the heat-island effect, absorb carbon dioxide, and reroute water to the rain collection tanks (Figs. 7 and 8).

The diagrams below display data obtained by using the ATHENA® Impact Estimator for Buildings. Located in Ontario, Canada, the ATHENA® Impact Estimator for Buildings was developed by the Sustainable Materials Institute. As part of the institute's mission, it leverages the life-cycle assessment in North America to promote sustainability in the built environment [23]. According to the developers, "robust life cycle inventory databases provide exact scientific cradle-to-grave information about building materials and products, transport, and construction and demolition activities" [28]. The Athena Institute connects designers to the power of life-cycle analysis without requiring them to become LCA experts themselves [28].

Any part of a building has the potential to be modeled using the Impact Estimator when the bill of materials has been provided. Using simple inputs, the Impact Estimator can create a bill of materials for users who do not have one. Examples include [24] foundations, footings, slabs, all below- and above-grade structure and envelope, windows and doors, and building interiors. Based on a 60-year life cycle, the study examines the overall building's life cycle. According to ISO 14040, we

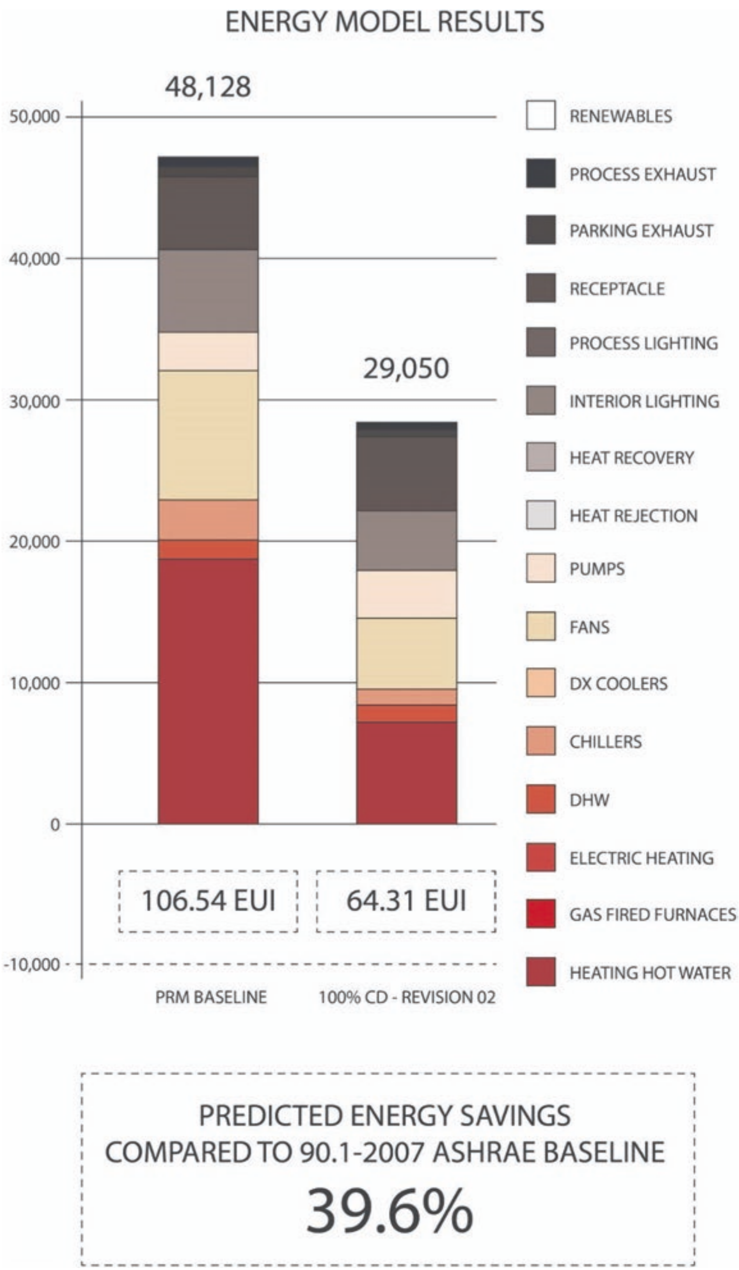

Fig. 6 Energy model results. (Original diagram credit: Info from architects)

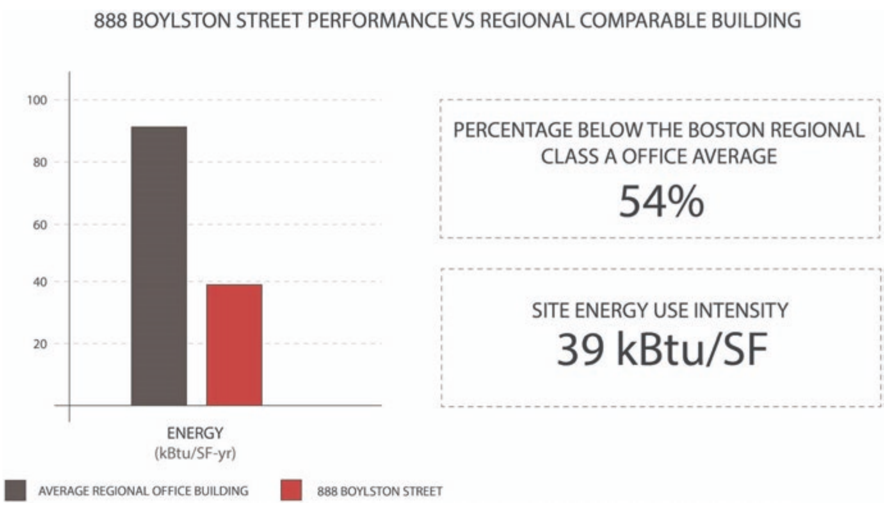

Fig. 7 Performance comparison to average regional office building.

Fig. 8 Facade, photovoltaics, and wind turbine integration. Credit: FXCollaborative Architects LLP

can compare up to five design scenarios according to the US Environmental Protection Agency's environmental impact categories [23]. In this study, the following environmental metrics were used: Global Warming Potential, Smog Potential, Acidification Potential, Non-renewable Energy, Eutrophication Potential, and Ozone Depletion Potential. As inputs to the Impact Estimator, a series of factors related to the building are considered in order to calculate the life-cycle impact of each factor on the above categories. There are five assemblies that consist of information on the project: foundations, floors, columns and beams, roofs, and walls (Figs. 9 and 10).

Fig. 9 Envelope materials and integrated sustainable strategies. Credit: FXCollaborative Architects LLP

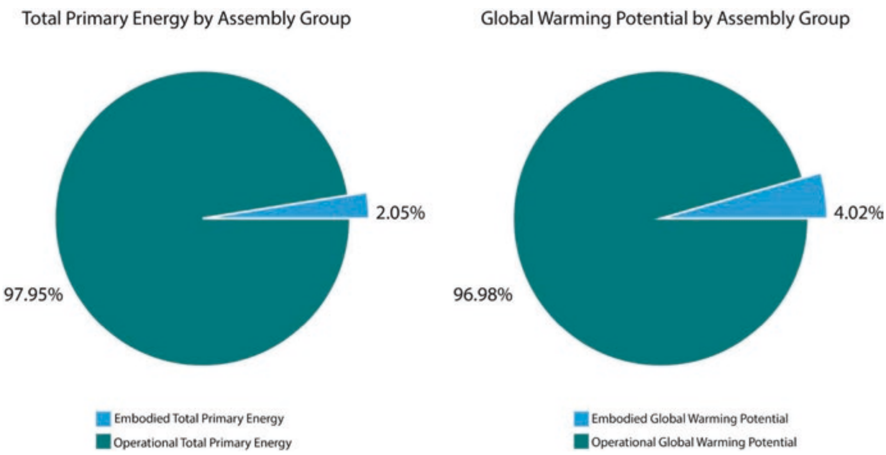

Fig. 10 Left: Operational versus embodied energy; right: global warming potential

A comparison is made between operating and embodied in both primary energy and global warming potentials. Operating accounts for a greater share in both charts.

Figure 11 displays the comparison between different constructional categories that are used in this building. The report compares the amount of CO_2 emissions that each category can have on the environment.

Figure 12 displays the comparison between different constructional categories that are used in the case study. The report compares the amount of O_3 emissions that each category contributes.

Conclusion

888 Boylston Street sets a precedent for the possibilities of sustainable buildings in US cold climate regions and serves as a model where educational tours on sustainable design are held. The design includes natural elements such as light and air in addition to biophilic elements such as the rooftop garden and green wall. As a mid-high-rise building that is comprised of 70% glass, 888 Boylston Street showcases just how environmentally friendly and sustainable large-glazed buildings can be. While the roof wind turbines might be the element of the building that catches the attention of most passersby, 888 Boylston Street has much more to offer in regard to its envelope, sustainable strategies, and operational and embodied energy.

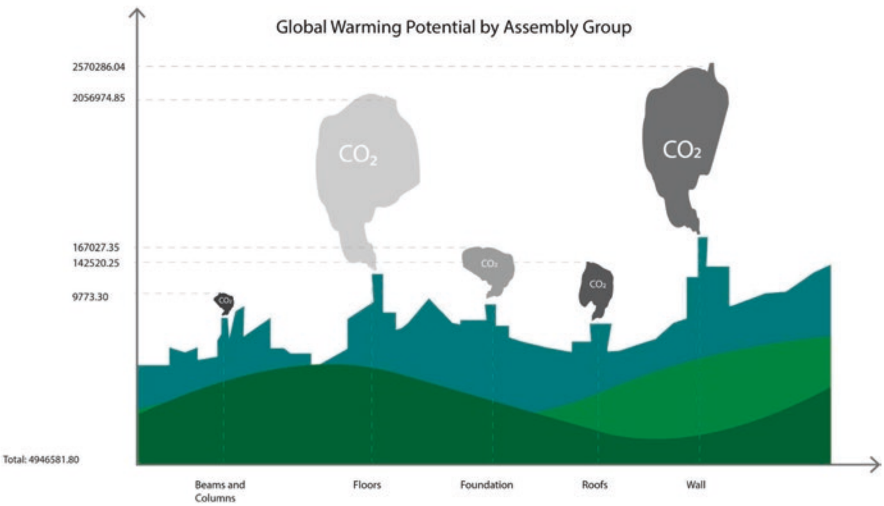

Fig. 11 Global warming potential

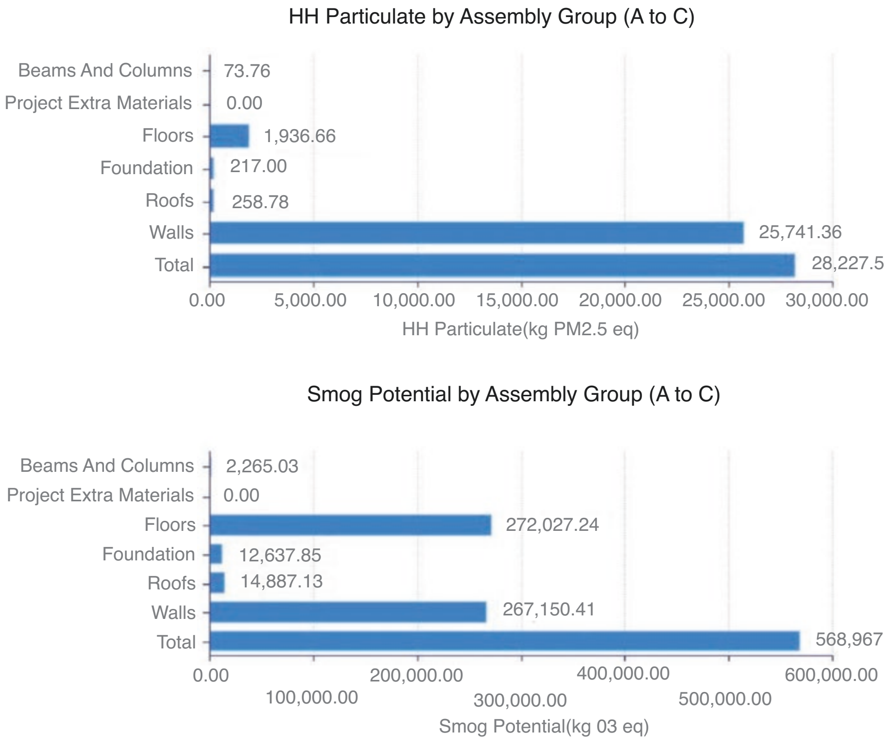

Fig. 12 Human health particulate and smog potential

Case Study: CLT Passivhaus

Architect: Generate Architects

Introduction

Generate, in collaboration with Placetailor, delivered the world's first fully integrated Cross-Laminated-Timber (CLT) Passivhaus demonstration project. The project is set to be located in the Roxbury neighborhood of Boston, MA. This project is a response to both global warming and urban density issues. The collaboration between Placetailor and Generate will make it possible to propose sustainable construction for mid-size and, in the future, high-rise buildings. Generally, this is a typology of housing delivery method that focuses on climate and community [29]. In terms of carbon footprint, the building aims to reach Passivhaus standards and is expected to be net-zero carbon in operation. Boston has a cold climate, which makes well-insulated exterior walls quite practical in this setting (Fig. 13).

Fig. 13 CLT Passivhaus. (Credit: Generate | Placetailor)

Roxbury is one of the 23 official neighborhoods in Boston, MA, located south of the central business district. Identified as a cold continental climate, Boston's weather includes warm summers and very cold and snowy winters. Boston is known to have a relatively unstable climate with alternating days of stormy and clear weather due to different air masses colliding from different directions [18]. Similar to Chicago, Boston's location along the water can result in relatively cool temperatures in summer due to cold current flows above the sea. Boston averages 47 inches of rain per year, 48 inches of snow per year, and slightly below the national average of sunny days per year [19]. The average temperature in Boston ranges from a high of 82 °F in the summer to a low of 19 °F in winter [19]. As heating consumes more energy than any other building systems in the Boston climate, passive techniques can and have been utilized to better provide thermal comfort indoors [20]. Air barriers and continuous thermal insulation are two techniques that can help with thermal bridging. In some areas in Boston, the water levels are also a concern. Many historical buildings contain elevated entryways to help combat possible flooding [21]. While many of the climatic characteristics of Boston can be combated with mechanical systems, these methods are not sustainable when compared to smart passive systems and other efficient sustainable strategies (Fig. 14).

Sustainable Features

The CLT Passivhaus includes a variety of spaces and techniques related to sustainable features and methods of construction. In addition to 14 residential units, the building includes a co-working space accessible to the local community on the ground floor (Fig. 13). A mix of housing types will be available in the 14-unit Model C building, ranging from studio apartments to 3-bedroom apartments. On the ground floor, there will be affordable commercial space for local businesses. Because the building is located in the city of Boston and close to public transportation, Placetailor was not required to provide parking [30]. The building will highlight the unique benefits of a prefabricated kit-of-parts for developing workforce housing that is both healthy and carbon positive (Figs. 15 and 16).

Fig. 14 Climatic data, dry-bulb temperature, wind roses, and psychrometric chart

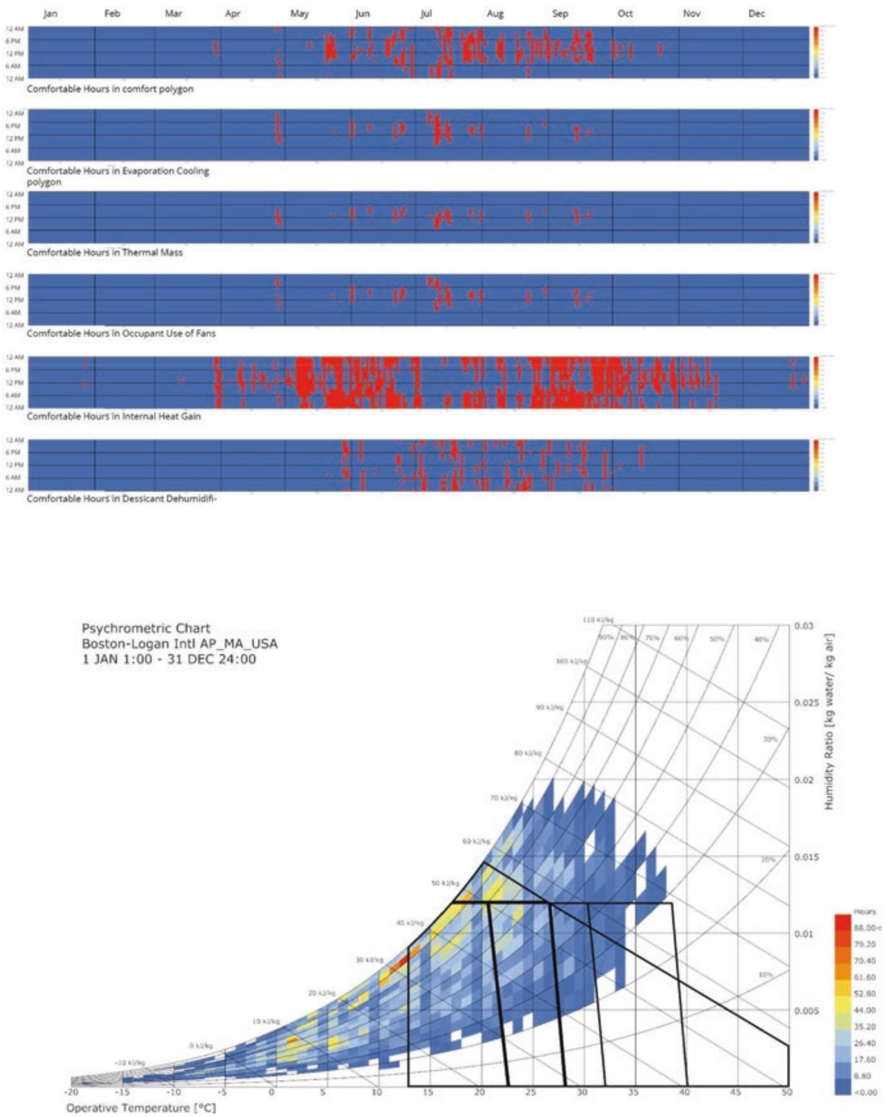

Fig. 14 (continued)

Despite the concrete foundation, all other elements of the building are made of CLT panels – an engineered wood made of laminated timber sections [31]. As illustrated in Fig. 17, CLT panels of varying thicknesses make up the floor, interior partitions, exterior walls, and roof assemblies of the Model C [30]. A high-density cellulose thermal panel is to be installed on the interior of the exterior assembly, and

Fig. 15 The building section displays the array of interior spaces including the 14 residential units and co-working space. Credit: Generate | Placetailor

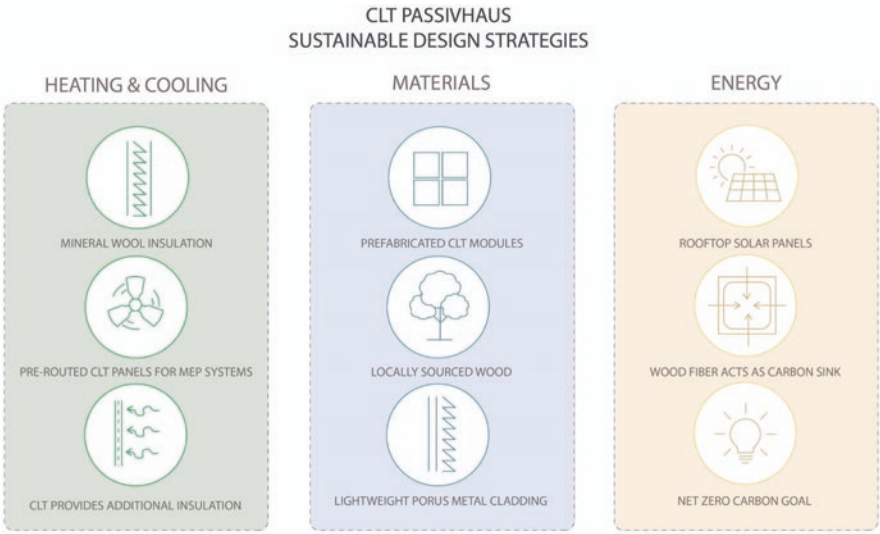

Fig. 16 Sustainable strategies

a wood-fiber board must be used on the exterior. Clean and modern, but warm and spacious, CLT walls give interior spaces a sense of comfortable living [32]. The building is also designed to reduce the amount of radiation it receives and to insulate against heat and cold. Mineral wool and CLT will be used as insulation on the walls [31].

Fig. 17 CLT elements such as beams, columns, and ceilings can be seen from this render view. (Credit: Generate | Placetailor)

Envelope

The exterior elements of the building are mainly CLT panels, glazing, and frames. The CLT's cellular structure and envelope act as carbon sinks by capturing carbon dioxide during the life of the building and replacing traditional concrete and steel materials that cause significant carbon dioxide emissions [29]. Additionally, cladding for the building will be made of lightweight porous metal. As shown in Fig. 18, in this case, scaffolding will not be needed during construction because it is prefabricated [31]. The corrugated metal siding will be equipped with a rainscreen air gap. The metal panels themselves will be perforated. As a result, select views from the exterior of the building will allow for glimpses of the exposed wood inside of the building. Additionally constructed of CLT, the sawtooth roofline is oriented toward south for maximum solar PV exposure [30]. Rooftop solar panels are mounted easily on this system due to the CLT roof canopy.

Operational Versus Embodied Energy

A Model C demonstration project was designed to generate net-zero carbon emissions by measuring both the embodied energy of the building and its operating energy. Any excess energy was compensated for by carbon offsets [32]. When

Fig. 18 Lightweight porous metal cladding will be used as the envelope of the building. (Credit: Generate | Placetailor)

compared to traditional buildings constructed with conventional steel or concrete, the Model C project reduced total embodied carbon emissions by less than 50% [30]. Due to the CLT construction, fireproofing materials can be reduced, along with the use of dyed plaster or drywall. Additionally, exposed CLT walls and ceilings can help reduce the use of harmful materials [31]. The CLT panels are in fact a carbon sink due to the high amounts of wood fiber, which allows them to address both operational and embodied energy with one solution [31]. As shown in Fig. 19, the CLT panels which will be used in construction are set to be locally sourced from Montreal, Canada, and trimmed locally by panel manufacturer Bensonwood in Keene, New Hampshire [30].

The operational energy requirements of the building rely on a heat pump for cooling and cost-effective electric-baseboard system for heating. The mechanical ventilation for air circulation is set to be supplied by a semi-centralized system where one system supplies four housing units. The building's source of hot water and part of the electricity will be supplied from a gas-fueled combined heat and power (CHP) plant. Current calculations show that the use of the CHP will lower greenhouse gas emissions when compared to using the heat pump for traditionally heated water [30]. The building also includes off-site prefabricated modular

Fig. 19 Locally sourced and trimmed CLT will be exposed in indoor spaces. (Credit: Generate | Placetailor)

bathrooms that can be hoisted and installed easily, enhancing the project's timeline and reducing construction waste [29]. This material is more energy-efficient. A Passivhaus already has a low energy demand, so in order to reduce the MEP requirements, the CLT panels can be pre-routed to incorporate the system (Fig. 20).

The diagrams below (Figs. 21, 22, and 23) display data obtained by using the ATHENA® Impact Estimator for Buildings. Located in Ontario, Canada, the ATHENA® Impact Estimator for Buildings was developed by the Sustainable Materials Institute. As part of the institute's mission, it leverages the life-cycle assessment in North America to promote sustainability in the built environment [18]. According to the developers, "robust life cycle inventory databases provide exact scientific cradle-to-grave information about building materials and products, transport, and construction and demolition activities" [33]. The Athena Institute connects designers to the power of life-cycle analysis without requiring them to become LCA experts themselves [33].

Any part of a building has the potential to be modeled using the Impact Estimator when the bill of materials has been provided. Using simple inputs, the Impact Estimator can create a bill of materials for users who do not have one. Examples include [19] foundations, footings, slabs, all below- and above-grade structure and envelope, windows and doors, and building interiors. Based on a 60-year life cycle, the study examines the overall building's life cycle. According to ISO 14040, we can compare up to five design scenarios according to the US Environmental

Fig. 20 Envelope materials. (Credit: Generate | Placetailor)

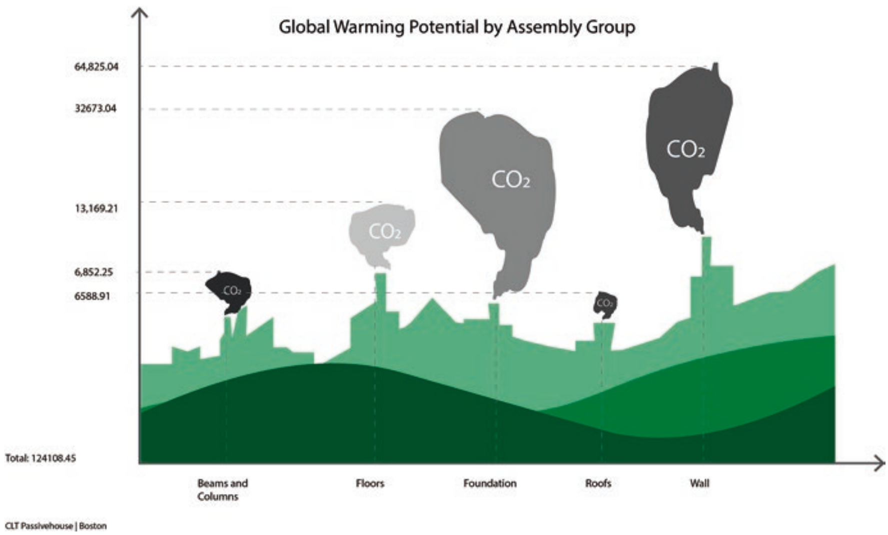

Fig. 21 Global warming potential

Protection Agency's environmental impact categories [18]. In this study, the following environmental metrics were used: Global Warming Potential, Smog Potential, Acidification Potential, Non-renewable Energy, Eutrophication Potential, and Ozone Depletion Potential. As inputs to the Impact Estimator, a series of factors related to the building are considered in order to calculate the life-cycle impact of

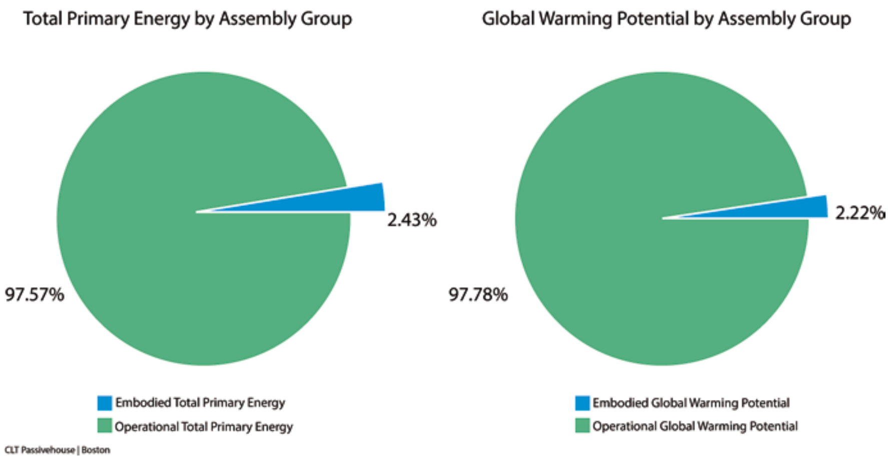

Fig. 22 Left: operational versus embodied energy; right: global warming potential

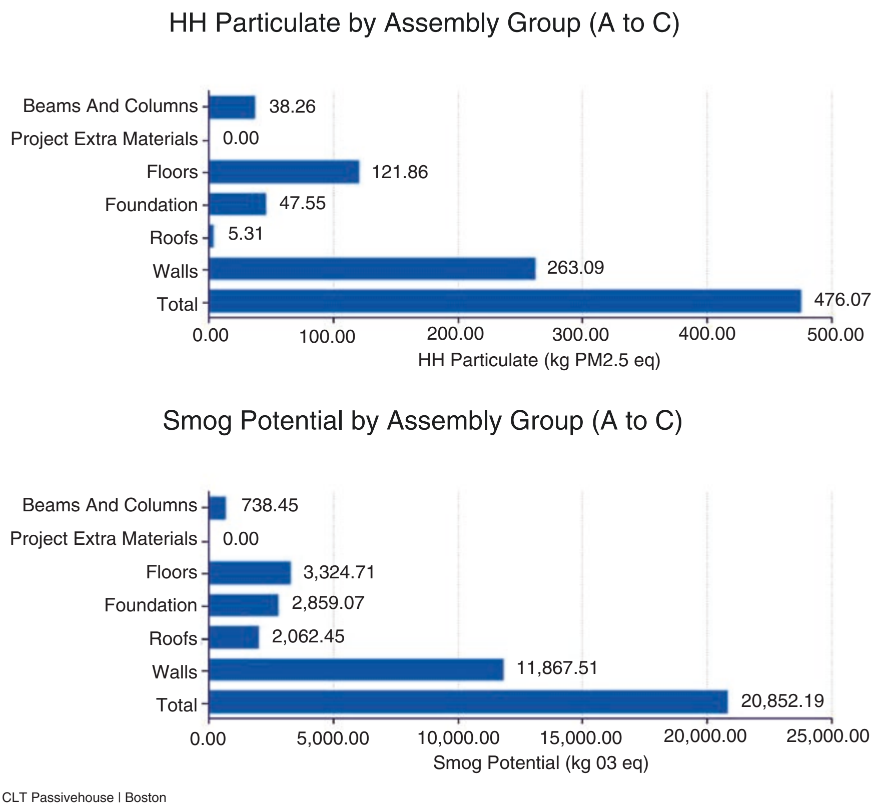

Fig. 23 Human health particulate and smog potential

each factor on the above categories. There are five assemblies that consist of information on the project: foundations, floors, columns and beams, roofs, and walls.

Figure 21 displays the comparison between different constructional categories that are used in the case study. The report compares the amount of CO_2 emissions that each section can have on the environment.

A comparison is made between operating and embodied in both primary energy and global warming potentials. Operating accounts for a greater share in both charts.

Figure 23 displays the comparison between different constructional categories that are used in the case study. The report compares the amount of O_3 emissions that each section can have on the environment.

Conclusion

Not only does the CLT Passivhaus serve as a precedent for net-zero projects in the USA, but it also serves as an example of fully integrated CLT construction. The project is a response to both global warming and urban density issues. Reacting to Boston's cold climate, both passive and active techniques in the building aid in reaching this net-zero goal. When compared to traditional buildings constructed with conventional steel or concrete, the Model C project reduced total embodied carbon emissions by less than 50%. With the addition of locally sourced CLT, it is clear that the CLT Passivhaus prioritizes sustainability and is deserving the title the world's first fully integrated CLT Passivhaus demonstration project.

Case Study: Golisano Institute for Sustainability

Architect: FXFOWLE, New York City, NY.

Architect of Record: SWBR, Rochester, NY

Introduction

The Golisano Institute for Sustainability (GIS) at Rochester Institute of Technology is a LEED Platinum building that not only serves as a laboratory for scientific research on sustainable technology but itself exemplifies energy efficiency and high-performance systems. Designed by FXFowle (NYC) and SWBR in Rochester, NY, the Golisano Institute for Sustainability is located in Rochester, NY. Designed for a very cold climate region, the building includes a high-performance facade system that helps reduce the overall carbon footprint. Since its completion in 2013, the building has won multiple awards, including the 2014 National Award of Excellence from the Design Build Institute of America (DBIA), and was titled the best project in the Green Project category by Engineering News Record New York [34]. It has earned LEED Platinum certification, which is the highest standard in the certification system. This writing aims to investigate the material involvement with specific attention to the envelope and its relationship to the overall sustainable status of the structure (Fig. 24).

Identified as a cold continental climate, Rochester is characterized by warm summers and snowy freezing winters. Similar to many of the cities in the included case studies, Rochester is located near a body of water. The southern shoreline of Lake Ontario reaches along the northern portion of Rochester. As a result, much of the snow is a direct result of the "lake effect," in which cold air crosses warmer water, resulting in clouds, precipitation, and snow [35]. Rochester averages 33 inches of rain per year, 77 inches of snow per year, and below the national average of sunny days per year [36]. The average temperature in Rochester ranges from a high of 82 °F in summer to a low of 17 °F in winter [36]. With the help from the US Department of Energy, the Passive Solar Industries council has set guidelines for climate-reactive passive strategies employed in the Rochester region [37]. While this information is specifically targeted to residential homes, much of the climate combatant information can also relate to larger structures such as the Golisano Institute for Sustainability. Some of these guidelines include increasing thermal resistance and increasing south-facing glazing up to 7% of the building's total floor

Fig. 24 Golisano Institute for Sustainability. Credit: David Lamb

area. Natural cooling and fully insulated basement walls are additionally suggested. As part of New York State's Genesee-Finger Lakes Region, Rochester has additionally been included in Stockholm Environment Institute's plan for combating climate change, which includes support for structures that are energy efficient and reduce waste [38] (Fig. 25).

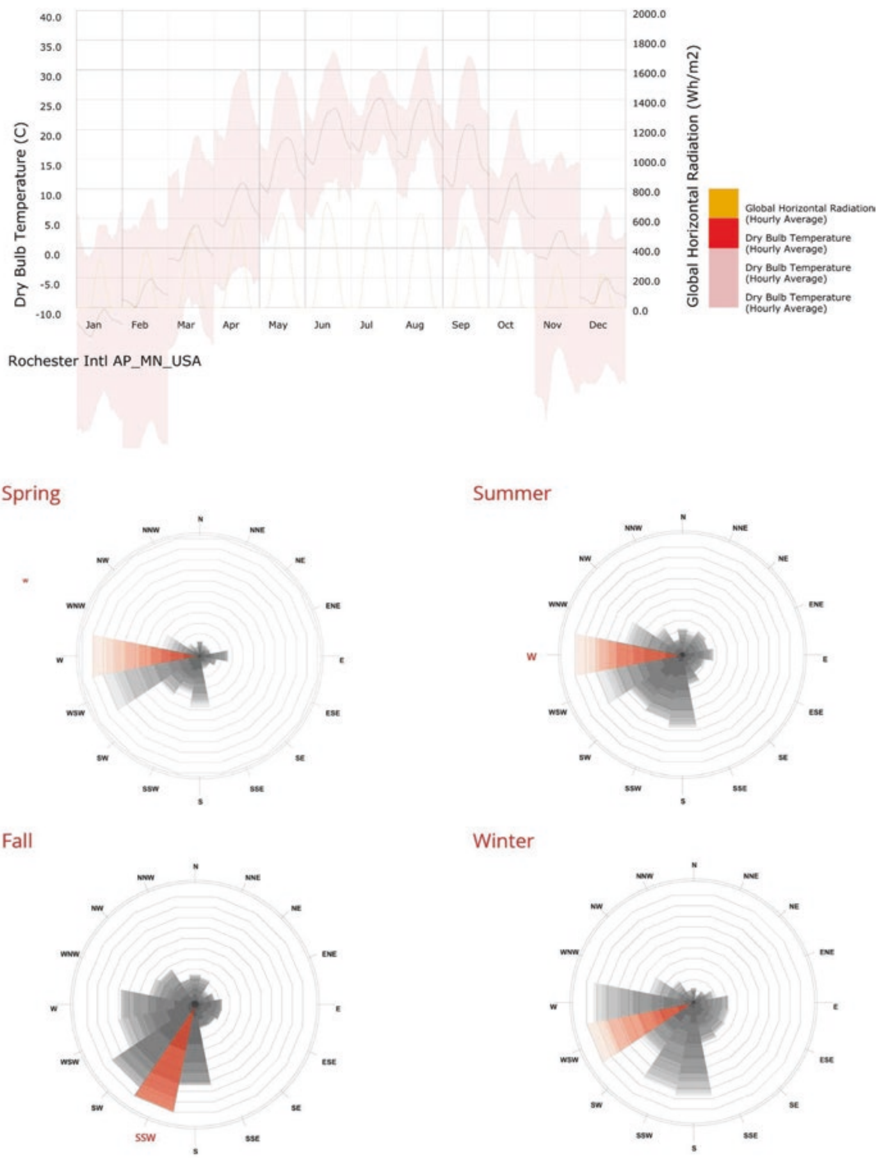

Fig. 25 Climatic data, dry-bulb temperature, wind roses, and psychrometric chart

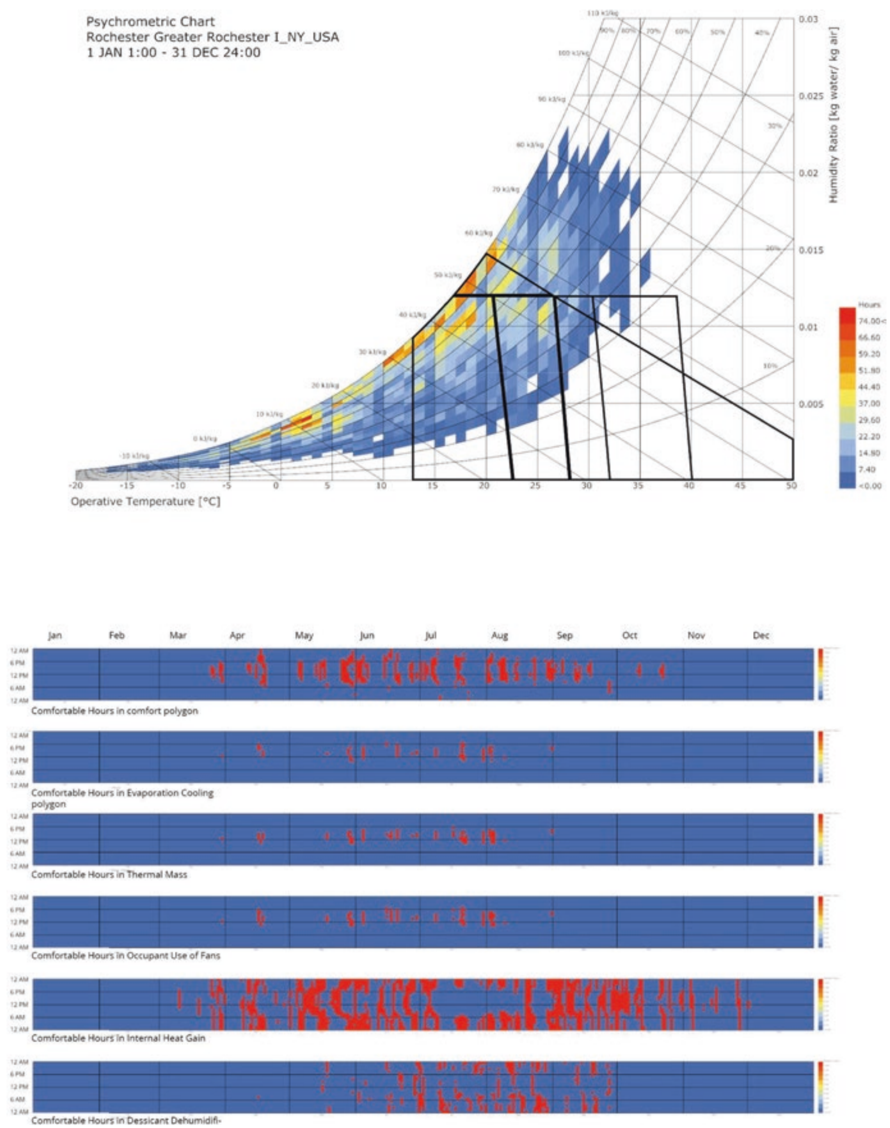

Fig. 25 (continued)

Sustainable Features

The building systems and envelope are both involved in the sustainable features utilized in the design of the Golisano Institute for Sustainability. In a similar manner, both active and passive strategies are central sustainable design features that contribute to the building's LEED Platinum status. Together all sustainable features reduce

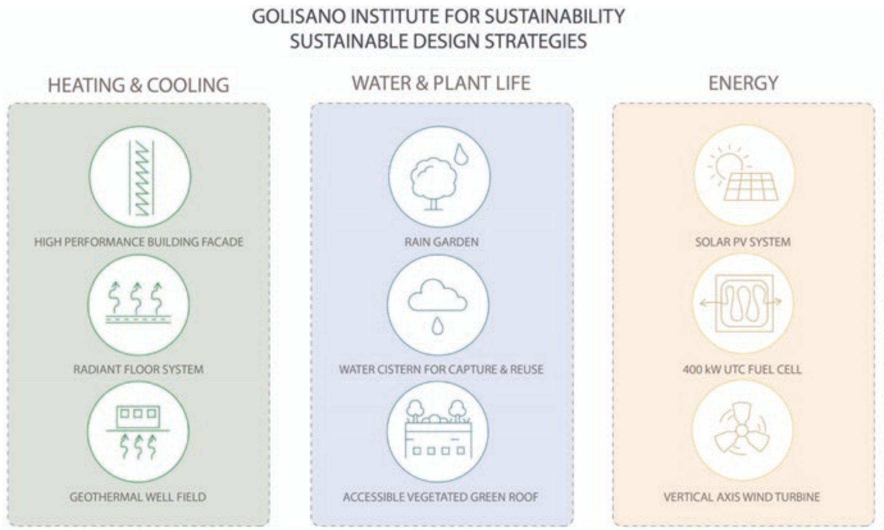

Fig. 26 Sustainable strategies, original diagram. (Credit: http://www.swbr.com/wp-content/uploads/2014/03/rit-gis-case-study_lo.pdf)

the annual carbon footprint of the building by 61%, meeting the AIA 2030 goal of 60% [39]. Other sustainable statistics show that the building has a total annual water saving of 75%, utilizes 88% forest stewardship-certified wood, and recycles nearly 80% of construction waste [39]. Some of the notable features included in the design that contribute to these statistics are vertical-axis wind turbines on-site, radiant flooring, geothermal well, solar shading controls, high-performance facade, green roof and walls, and roof photovoltaic (PV) system (Fig. 26).

Envelope

The envelope of the Golisano Institute for Sustainability alone contributes up to 15% of the total energy savings of the design [39]. The primary material utilized in the envelope of the building is glazing. As shown in Fig. 27, the glazing system consists of factory-assembled large units of glass situated in a thermally broken curtain wall system. A 40% vision glass or less was utilized to provide a triple-pane glazing performance while being only 1-inch thick [40]. In contrast, the spandrel glazing itself includes thermal insulation that is 4.5-inches thick. In areas of the envelope system where occupants are meant to sit near the glass, an innovative system of glazing termed the “perfect window” is utilized to improve thermal comfort. This system involves a double-pane window with a metal coating that is heated by electrical currents. In this system, when temperatures drop below 42 °F, the system

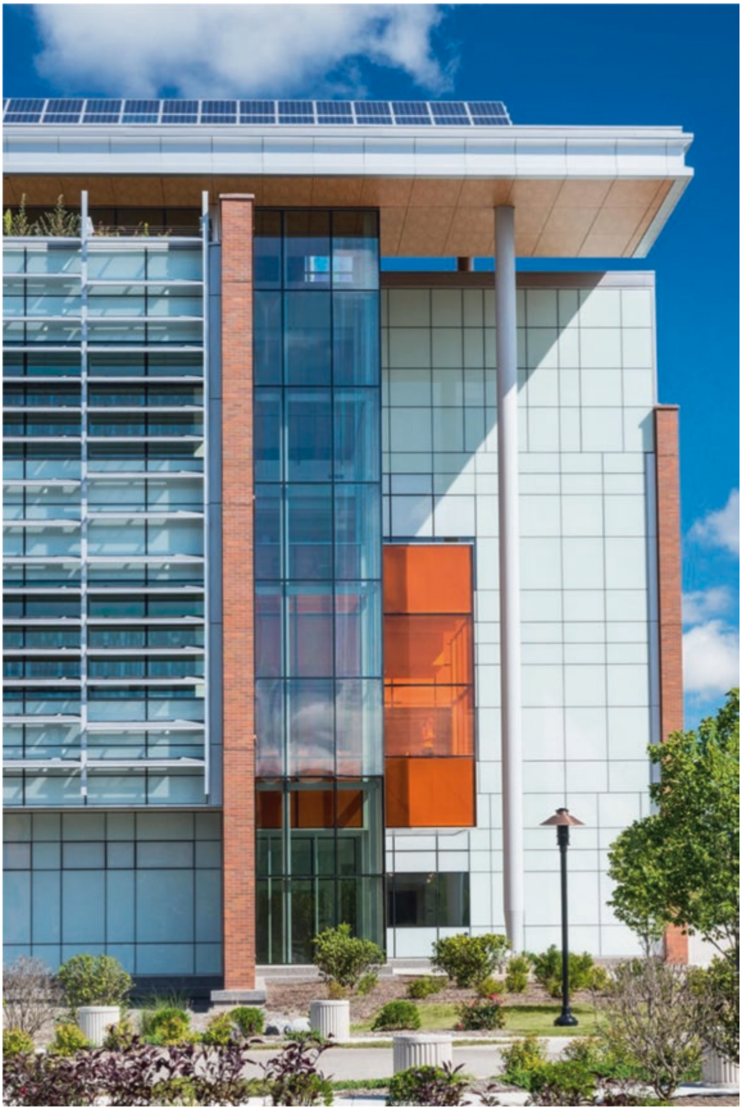

Fig. 27 Building Envelope. Credit: David Lamz

is heated providing optimal thermal comfort while also minimizing heat loss [40]. This electric-powered heated glass is essential for mitigating heat loss in the cold climate of Rochester, NY.

The envelope facade system of the Golisano Institute for Sustainability is different for different orientations. While both south and north facades are primarily glass, the east and west facades are constructed of masonry materials. In addition to

Fig. 28 Sun shading, PV systems, and green roof. Credit: Craig Shaw, Stratus Imaging

glazing, the south facade features solar shades that reduce solar heat gain by 70% [39]. The shading elements help reduce the building's cooling demand and allow a more efficient chilled beam technology. The building roof is equipped with 144 photovoltaic panels that generate an average of 45,000 kWh per year [41]. In addition to these energy-generating panels, the roof also houses 3300 square feet of vegetation and a butterfly habitat, as illustrated in Fig. 28 [39].

Operational Versus Embodied Energy

The Golisano Institute for Sustainability earned its LEED Platinum status by deploying both multiple operational and embodied carbon reduction strategies. The most visible techniques used to contribute to the operational energy of the building are the roof-mounted solar PV panels and the vertical-axis wind turbines located on-site. Currently, 170 solar panels are mounted on the roof of the building. This number of panels generates enough energy to power seven homes in New York. In addition to the wind and solar energy-generation strategies employed, additional strategies utilized include geothermal and a 400-kW fuel cell to supplement energy demands [42]. Additionally, an operational microgrid room incorporates data sensors, feedback loops, and control systems to monitor building performance and efficiency of operation [39]. With this system, a stand-alone power supply source is provided that consists of a lithium ion battery storage bank with a power of 50 kW\50 kWh.

With regard to the building's systems, many different interlocking and separate components and strategies work together to provide maximum comfort for the occupants. Air-handling units and terminal units are situated on the floors above grade while heating, cooling, and water conservation take place below grade. Included at the roof of the building is an exhaust terminal for the expulsion of air. While lighting and plug load controls exist throughout the entire building, the microgrid base exists on the first floor. This microgrid consists of the fuel cell, PV generation, batteries, lighting, and other miscellaneous loads. All of these components together contribute to an annual energy use of 112 kBtu/sf and a predicted energy saving beyond ASHRAE 90.1 of 57% [43].

The diagrams below display data generated using the ATHENA® Impact Estimator for Buildings. Located in Ontario, Canada, the ATHENA® Impact Estimator for Buildings was developed by the Sustainable Materials Institute. As part of the institute's mission, it leverages the life-cycle assessment in North America to promote sustainability in the built environment [39]. According to the developers, "robust life cycle inventory databases provide exact scientific cradle-to-grave information about building materials and products, transport, and construction and demolition activities" [36]. The Athena Institute connects designers to the power of life-cycle analysis without requiring them to become LCA experts themselves [36].

Any part of a building has the potential to be modeled using the Impact Estimator when the bill of materials has been provided. Using simple inputs, the Impact Estimator can create a bill of materials for users who do not have one. Examples include [35] foundations, footings, slabs, all below- and above-grade structure and envelope, windows and doors, and building interiors. Based on a 60-year life cycle, the study examines the overall building's life cycle. According to ISO 14040, we can compare up to five design scenarios according to the US Environmental Protection Agency's environmental impact categories [39]. In this study, the following environmental metrics were used: Global Warming Potential, Smog Potential, Acidification Potential, Non-renewable Energy, Eutrophication Potential, and Ozone Depletion Potential. As inputs to the Impact Estimator, a series of factors related to the building are considered in order to calculate the life-cycle impact of each factor on the above categories. There are five assemblies that consist of information on the project: foundations, floors, columns and beams, roofs, and walls (Fig. 29).

Figure 30 displays the comparison between different constructional categories that are used in the case study. The report compares the amount of CO_2 emissions that each section can have on the environment (Fig. 31).

A comparison is made between operating and embodied in both primary energy and global warming potentials. Operating accounts for a greater share in both charts.

Figure 32 displays the comparison between different constructional categories that are used in the case study. The report compares the amount of O_3 emissions that each section can have on the environment.

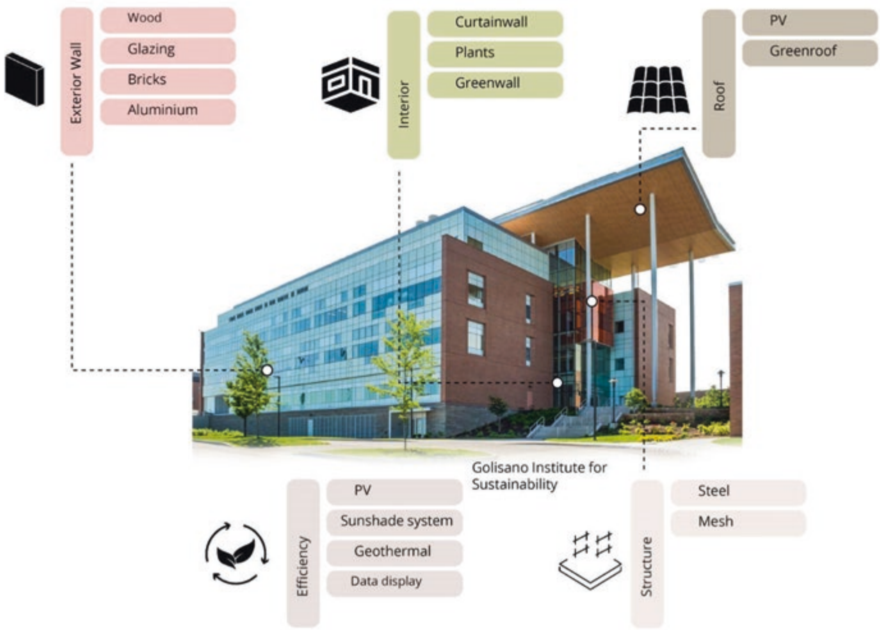

Fig. 29 Envelope materials and integrated sustainable strategies

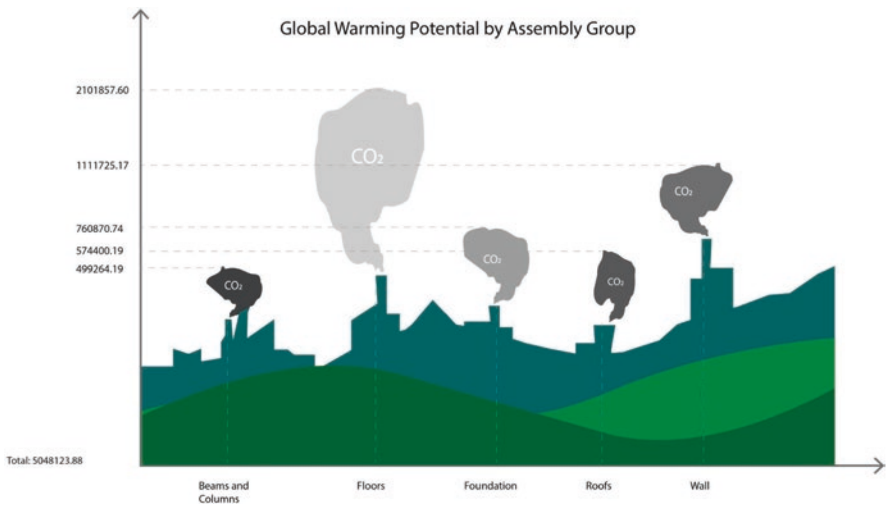

Fig. 30 Global warming potential

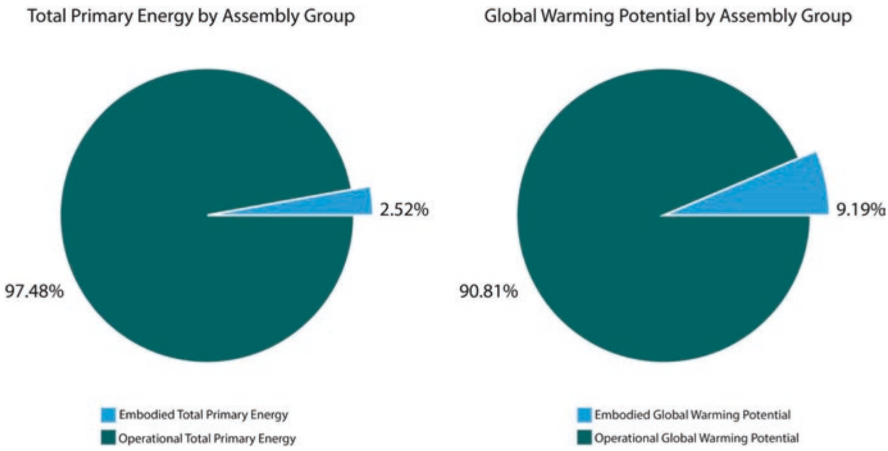

Fig. 31 Left: operational versus embodied energy; right: global warming potential

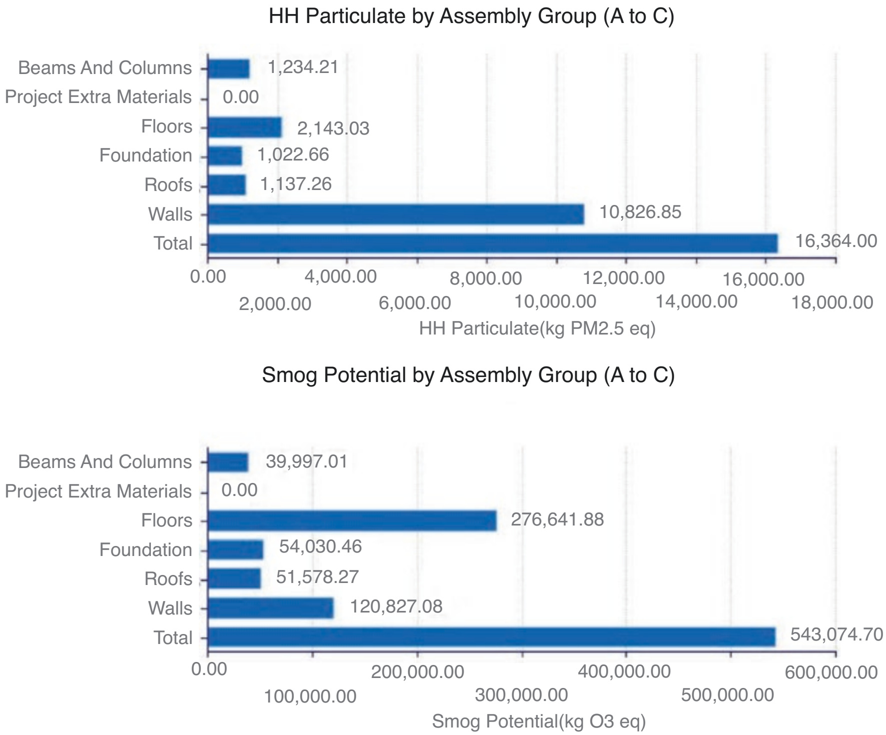

Fig. 32 Human health particulate and smog potential

Conclusion

Since its completion in 2013, the Golisano Institute for Sustainability (GIS) at the Rochester Institute of Technology (RIT) has won multiple awards, including the 2014 National Award of Excellence from the Design Build Institute of America (DBIA), and was titled the best project in the Green Project category by Engineering News Record New York. Along with a LEED Platinum certification, the design of this building exemplifies energy efficiency and regard for the environment. This feat is obtained through both passive and active strategies that relate to the envelope, operational, and embodied energy use in the building. With all strategies in place, the Golisano Institute for Sustainability serves as an ideal precedent of the region for the sustainable possibilities of lab and educational buildings.

Case Study: Orlando McDonald's Flagship

Architect: Ross Barney Architects

Introduction

The McDonald's Disney Flagship, located in Orlando, Florida, not only serves as a precedent for the sustainable possibilities of quick-serve restaurants but responds to the humid subtropical climate of its location. Designed by Ross Barney Architects in 2021, the building pushes the boundaries of ordinary McDonald structures through the use of photovoltaic glass panels, natural ventilation techniques, and on-site energy generation. Aside from energy generation of the building amounting to 100% of the building's needs, the materials used in construction and design strategies in place are paramount to the building's net-zero status. Specific attention is given to the V-shaped roof that responds to Florida's climate as well as the wood louvers and plant-covered walls. This writing aims to investigate this material involvement with specific attention to the envelope and its relationship to the overall net-zero status of the structure (Fig. 33).

Identified as a humid subtropical climate, Orlando winters are mild and short, while summers are hot and sunny. Orlando averages 52 inches of rain per year, 0 inches of snow per year, and above the national average of sunny days per year [44]. The average temperature in Orlando ranges from a high of 92 °F in summer to a low of 49 °F in winter [44]. In June to September, there are also frequent thunderstorms and muggy weather. Hurricanes are likely to hit Florida during the summer and early fall [45]. Prior to the invention of air conditioners and the widespread use of this technology, open and breezy dwellings were the ideal choice of homes in this climate. The air conditioning in modern homes makes them more comfortable despite being tightly insulated [46]. Additionally, there are two envelope concepts

Fig. 33 Orlando McDonald's Flagship. (Credit: Kate Joyce Studios, McDonald's Flagship—Orlando, Ross Barney Architects, 2020)

that are known to be efficient for Florida's climate: (1) a compact shape to reduce the exterior wall area and (2) continuous insulation to ensure that the building envelope has no interruptions. It is imperative that buildings in this climate zone are sealed tightly to avoid cool air indoors releasing outdoors and vice versa (Fig. 34).

Sustainable Features

The McDonald's Disney Flagship is part of a corporate McDonald strategy that aims to spread and implement net-zero energy-certified restaurants internationally. McDonald's global sustainability efforts will be informed by data, including progress toward the company's science-based target to reduce greenhouse gas emissions by 36% by 2030, compared with 2015 [47]. Disney's newly remodeled building is situated on the west side of the Disney property. In response to Florida's climate and its site location, the restaurant is covered in solar panels, creating a sustainable and healthy environment. The design features natural ventilation for about 65% of the time [48]. By doing so, the restaurant takes advantage of the humid subtropical climate.

As presented in Fig. 35, one of the key sustainable elements in the project's design is the use of green walls (Fig. 33). With the help of Florida-based architecture and engineering firm CPH, Ross Barney Architects designed the plant selection utilized in the walls [49]. The plants were chosen according to the subtropical climate of Orlando. They are equipped with a plant care system that works to keep their facades green throughout the year [49]. The plant care system sends automatic updates to an app that keeps those involved in the wall's design and maintenance updated on the green wall's condition [50]. The web-based system delivers the right amount of nutrients and water to the plants. Because the quantities of nutrients and water are monitored remotely, they can be adjusted easily [49]. In addition to these green walls, the company's logo is also incorporated into a lush garden wall that absorbs additional CO_2 [51]. In total, 1766 square feet of the living green walls are included in the project and help increase local biodiversity (Fig. 36).

Other sustainable strategies in place include paving materials that help reduce the heat island effect as well as pervious surfaces to redirect rainwater. Additionally

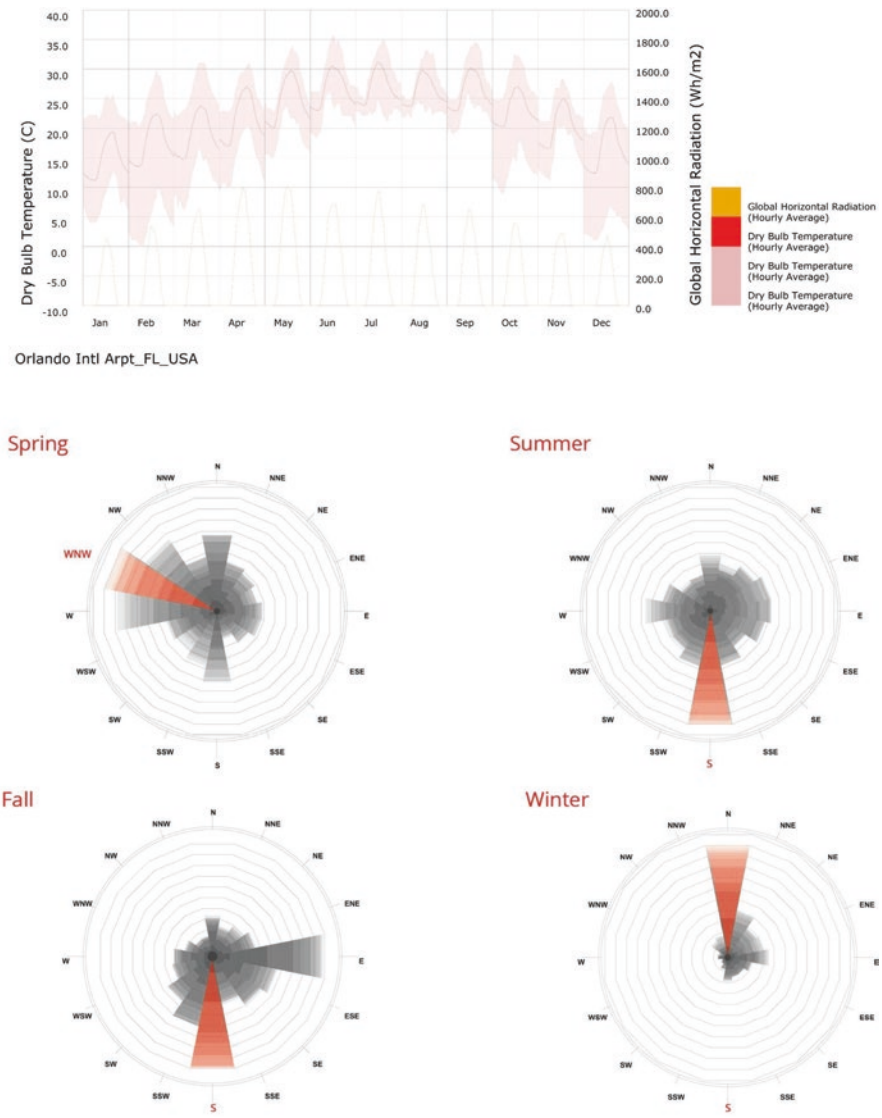

Fig. 34 Climatic data, dry-bulb temperature, wind roses, and psychrometric chart

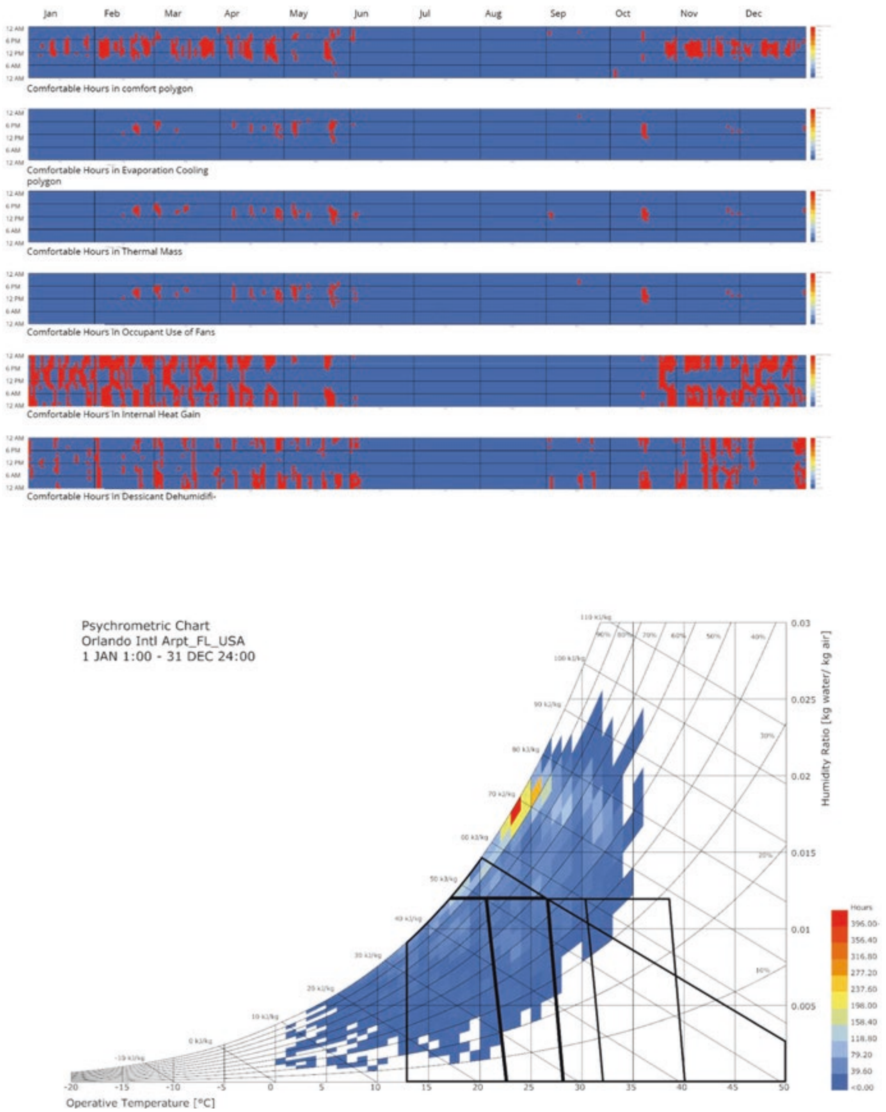

Fig. 34 (continued)

located on the exterior of the building and resembling an outdoor play structure, the building site features stationary bikes that allow users to pedal in place, ultimately harnessing that kinetic energy, and charge their devices [52]. This kinetic energy can also be used to light up a display of the McDonald's logo on one of the green walls. Sustainable and renewable energy generation of this sort represents the design commitment to a net-zero status as well as ingenuity and liveliness for all those who will visit the fast-service restaurant.

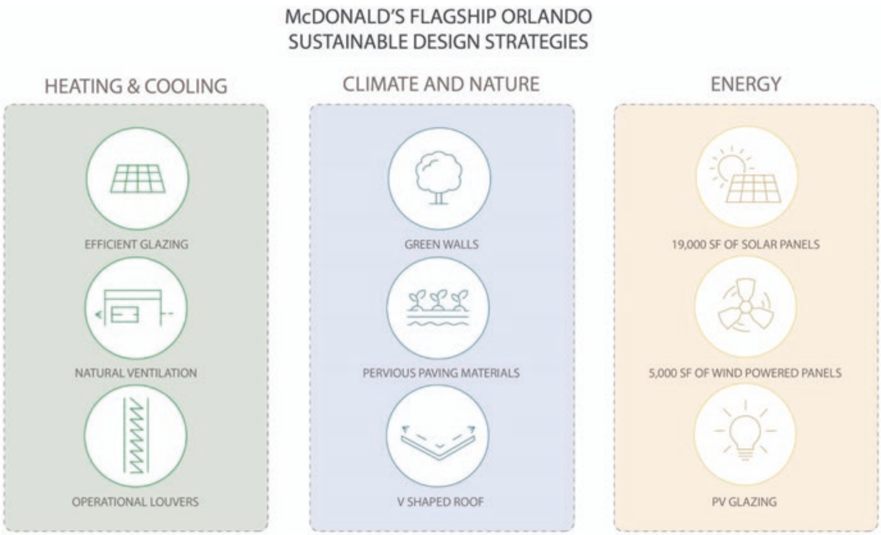

Fig. 35 Sustainable strategies

Fig. 36 A green wall equipped with a plant care system can be seen on the exterior of the building from the parking lot. (Credit: Kate Joyce Studios, McDonald's Flagship—Orlando, Ross Barney Architects, 2020)

Envelope

Although the building takes advantage of Orlando's humid subtropical climate through the use of natural ventilation, it also contains a high-efficiency system of glazing. With wood louvered walls and fans, the indoor dining area can be extended as an outdoor entrance. A specific and efficient type of automatic window, coined "jalousie windows," is utilized as the primary glazing material [48]. As shown in Fig. 37, temperature and humidity sensors in the exterior operate the windows to close automatically, and air conditioning is used instead of natural ventilation. In this way, the building functions similarly to vernacular Florida architecture prior to the invention of air conditioning where natural breezes are taken advantage of and used to cool indoor spaces. However, the dynamic aspect of the sensor system ensures indoor comfort even on the most humid of days.

Fig. 37 Operational "jalousie windows" and wood louvers are combined to provide shade and allow for natural ventilation when desired. (Credit: Kate Joyce Studios, McDonald's Flagship—Orlando, Ross Barney Architects, 2020)

Operational Versus Embodied Energy

The glazing system is not only operable but also integrated with photovoltaic (PV) panels. PV Glass panels with a size of 4809 square feet were manufactured by Onyx Solar and installed on the porch [48]. "Belnor Engineering's Onyx Solar photovoltaic glass" is the name of the specific glazing used in the building. With regard to its benefits, this type of glass can naturally illuminate various spaces with sunlight [53]. Additionally, it avoids UV and IR radiation while generating renewable energy [53]. Using these solar panels helps combine both active and passive properties. These panels both provide thermal and acoustic insulation [53] and consist of two layers of tempered glass, each of which is 14″ in height [51]. While the outermost layer is transparent, the interior layer is light gray [51]. A total of 192 units of 291 watt/unit, gray-finished crystalline silicon glass are utilized in this system, providing a power of 55.80 kWp. Additionally, 66 monocrystalline silicon solar cells are embedded in the glass of each unit [51]. As a result of the PV glass panel system, an average light transmittance of 36% is achieved. This amount provides increased light in the dining area of the porch [51].

Although the PV glazing system is responsible for providing increased light in the dining area of the porch, it is not the only means of energy generation found in the building design. Other energy-generation strategies include 18,727 square feet of PV panels and 25 smart off-grid parking lot lights. The building additionally utilizes low-flow plumbing fixtures and LED lighting. In total, these strategies produce more energy than the restaurant uses [48]. A large portion of the corporate goal to reach net zero has been achieved by using solar energy (Fig. 35). The design includes 19,000 square feet of traditional solar panels on its roof and canopy and 5000 square feet of wind-powered solar panels on the porch [51]. As a result, the building is capable of producing 679,000 kWh each year [51]. This energy generation is particularly important as it is utilized for the consumption of energy in the building's kitchen systems (Fig. 38).

The diagrams below display data obtained by using the ATHENA® Impact Estimator for Buildings. Located in Ontario, Canada, the ATHENA® Impact Estimator for Buildings was developed by the Sustainable Materials Institute. As part of the institute's mission, it leverages the life-cycle assessment in North America to promote sustainability in the built environment [50]. According to the developers, "robust life cycle inventory databases provide exact scientific cradle-to-grave information about building materials and products, transport, and construction and demolition activities" [53]. The Athena Institute connects designers to the power of life-cycle analysis without requiring them to become LCA experts themselves [53].

When the bill of materials has been provided, any part of a building has the potential to be modeled using the Impact Estimator. Using simple inputs, the Impact Estimator can create a bill of materials for users who do not have one. Examples include [51] foundations, footings, slabs, all below- and above-grade structure and envelope, windows and doors, and building interiors. Based on a 60-year life cycle,

Fig. 38 The underside of solar panels can be seen from the exterior dining area. (Credit: Kate Joyce Studios, McDonald's Flagship—Orlando, Ross Barney Architects, 2020)

the study examines the overall building's life cycle. According to ISO 14040, we can compare up to five design scenarios according to the US Environmental Protection Agency's environmental impact categories [50]. In this study, the following environmental metrics were used: Global Warming Potential, Smog Potential, Acidification Potential, Non-Renewable Energy, Eutrophication Potential, and Ozone Depletion Potential. As inputs to the Impact Estimator, a series of factors related to the building are considered in order to calculate the life-cycle impact of each factor on the above categories. There are five assemblies that consist of information on the project: foundations, floors, columns and beams, roofs, and walls (Figs. 39 and 40).

The figure displays the comparison between different constructional categories that are used in the case study. The report compares the amount of CO_2 emissions that each section can have on the environment (Fig. 41).

A comparison is made between operating and embodied in both primary energy and global warming potentials. Operating accounts for a greater share in both charts.

Figure 42 presents the comparison between different constructional categories that are used in the case study. The report compares the amount of O_3 emissions that each section can have on the environment.

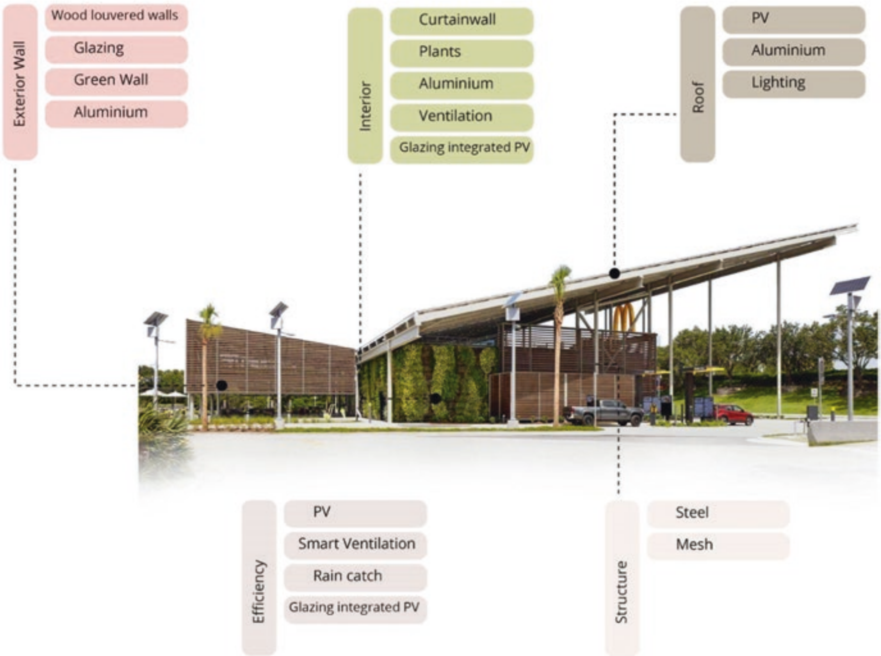

Fig. 39 Envelope materials and integrated sustainable strategies

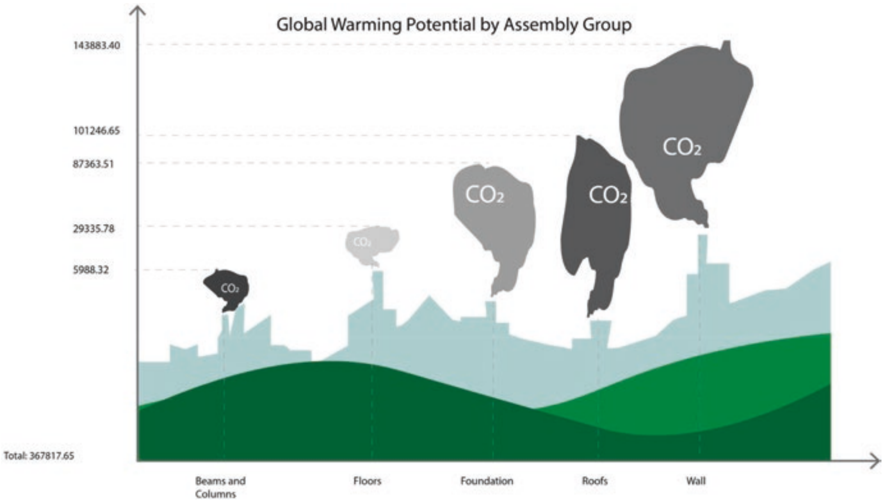

Fig. 40 Global warming potential

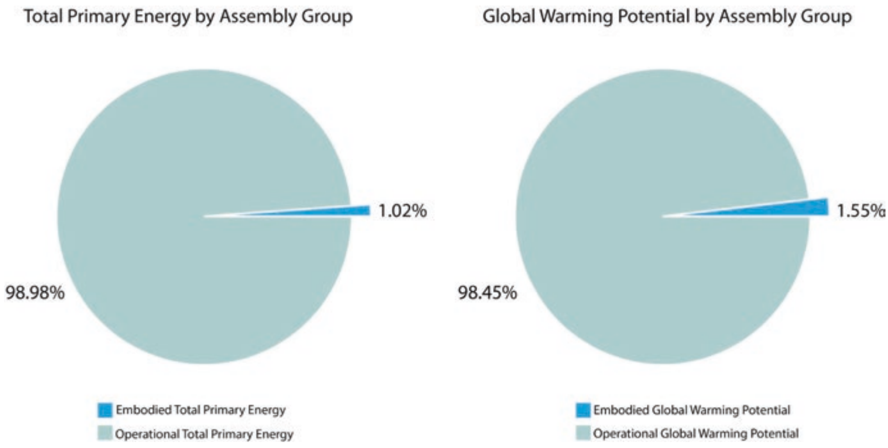

Fig. 41 Left: operational versus embodied energy; right: global warming potential

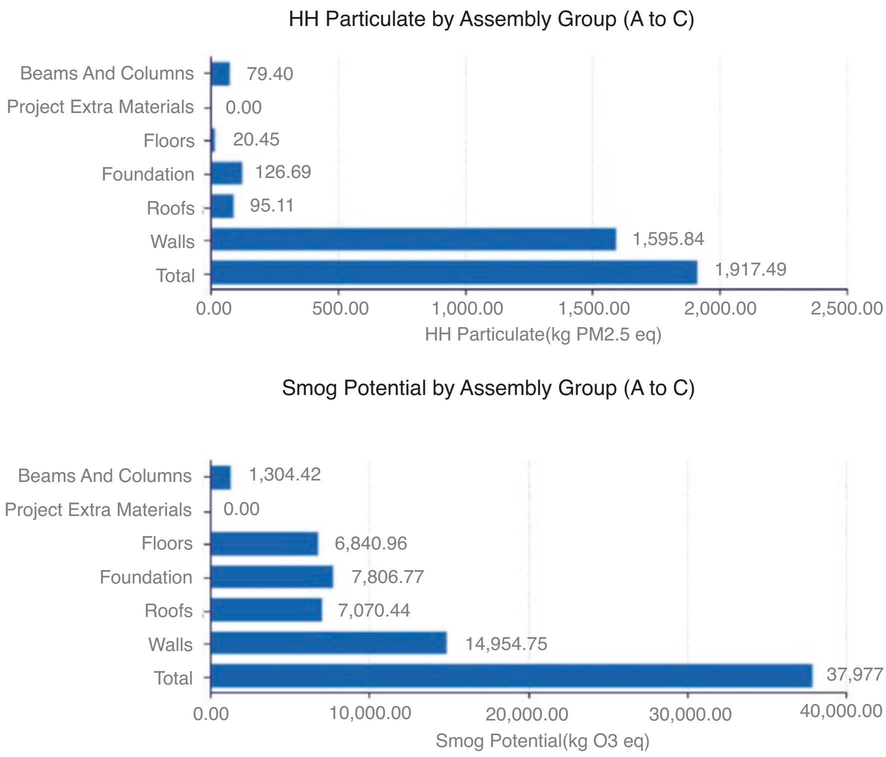

Fig. 42 Human health particulate and smog potential

Conclusion

Since its construction in 2021, the Orlando McDonald’s Flagship building has garnered a large amount of press and attention due to the sustainable features included. Both the passive and active strategies employed by Ross Barney Architects are necessary for the LEED Platinum status and regard that the design holds. Strategies like the louvered walls or V-shaped roof that respond to Orlando’s humid subtropical climate showcase the effort and effectiveness of these passive strategies in the building’s design. These strategies, combined with ingenuitive PV and other energy-generation techniques, all contribute to the realized design of the Orlando McDonald’s Flagship building and its place as an innovative and exciting precedent for net-zero fast-service restaurants.

Case Study: McDonald’s Flagship, Chicago

Architect: Ross Barney Architects

Introduction

The McDonald’s Flagship, located in Chicago, Illinois, not only showcases the company’s corporate commitment to sustainability but also responds to Chicago’s continental climate and the city’s density through incorporation of green spaces. Designed by Ross Barney Architects in 2018, the building incorporates a solar pergola encompassing a pure glass box as the LEED Platinum design strategy. Located on the site of the long-standing, well-known “Rock ‘n Roll” McDonald’s, the design reuses elements from the 1985 structure while prioritizing pedestrian accessibility. The design brings natural elements, such as light and trees, indoors and utilizes permeable paving to reduce the heat island effect. Serving as the first commercial use of CLT in the city of Chicago, the design has been awarded a LEED Platinum status. This writing aims to investigate the role of material selection in the project with specific attention to the envelope and its relationship to the overall sustainable status of the structure (Fig. 43).

Identified as a continental climate, Chicago’s weather is not only affected by the sun and wind but also by Lake Michigan. Chicago is located directly on Lake Michigan and touches the southwestern portion of this piece of the Great Lakes. One way in which Lake Michigan affects the climate of Chicago is by moderating temperature swings due to its thermal mass [54]. Referring to the city’s nickname, “the windy city”, the lake also allows air to pass over its surface, leading to increased snowfall and high winds. Chicago averages 38 inches of rain per year, 35 inches of snow per year, and slightly below the national average of sunny days per year [55]. The average temperature in Chicago ranges from a high of 84 °F in summer to a low

Fig. 43 McDonald's Flagship, Chicago. (Credit: David Thaddeus)

of 19 °F in winter [55]. During a span of 5 days in 1995, the city of Chicago endured extraordinarily high temperatures that ultimately led to several hundred deaths [56]. Since then, the city of Chicago has made it a priority to identify urban heat areas and to adopt heat-reducing strategies in the construction and design of these areas. With the help from the US Department of Energy, the Passive Solar Industries council has set guidelines for climate-reactive passive strategies employed in the Chicago region [57]. While this information is specifically targeted to residential homes, much of the climate combattant information can also relate to larger structures such as the McDonald's Flagship. These guidelines include techniques like added insulation and sun-tempering to allow for efficient natural heating and cooling of spaces specific to Chicago's climate (Fig. 44).

Sustainable Features

Located in the center of Chicago, a pedestrian-oriented quick-serve restaurant with a rooftop orchard stands out among the traditional McDonald restaurants many associate with the company name. However, the McDonald's Flagship location in Chicago includes not only a sustainable site design but also energy reduction strategies and an efficient material selection. The solar pergola itself, which encompasses the structure below, consists of over 1000 solar panels [58]. The pergola extends well beyond the interior structure beneath it, attempting to connect both of the interior and exterior spaces below. This structure sets a new precedent for car and pedestrian traffic in an attempt to rebalance the two user groups. Taking up an

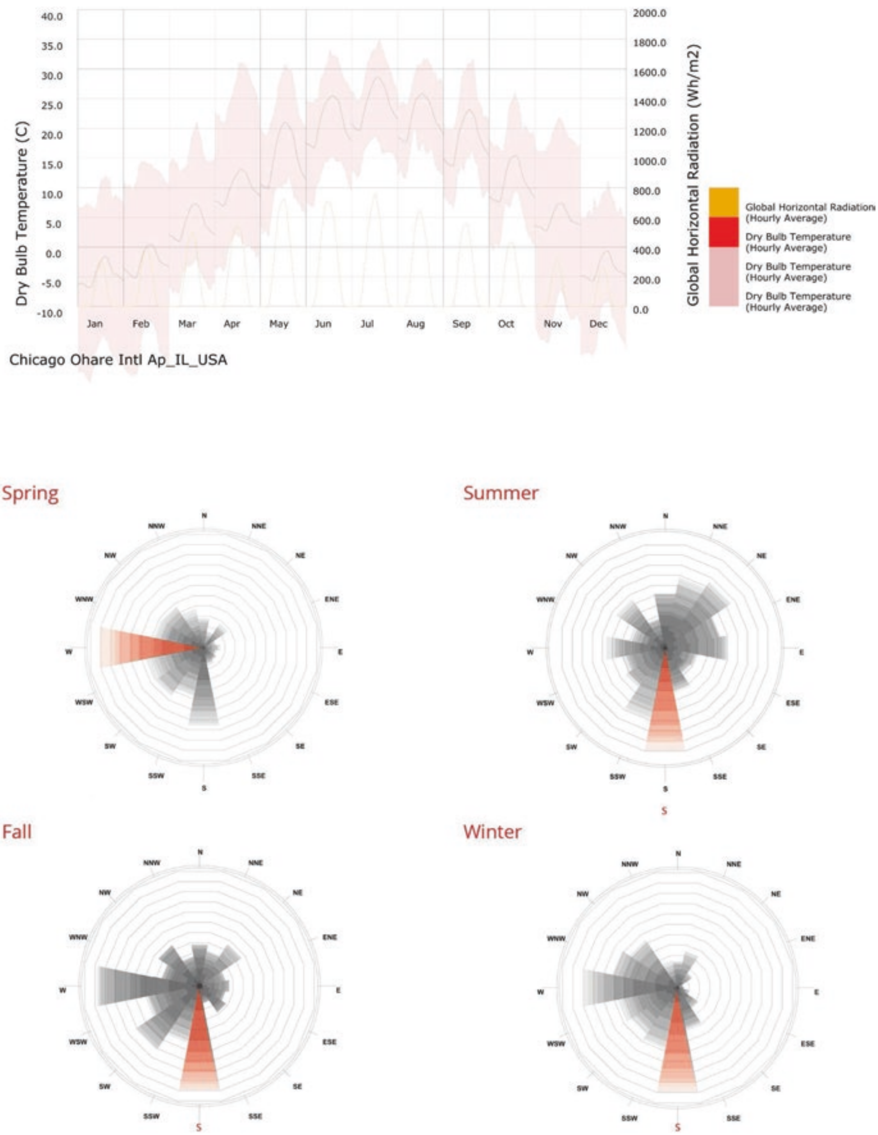

Fig. 44 Climatic data, dry-bulb temperature, wind roses, and psychrometric chart

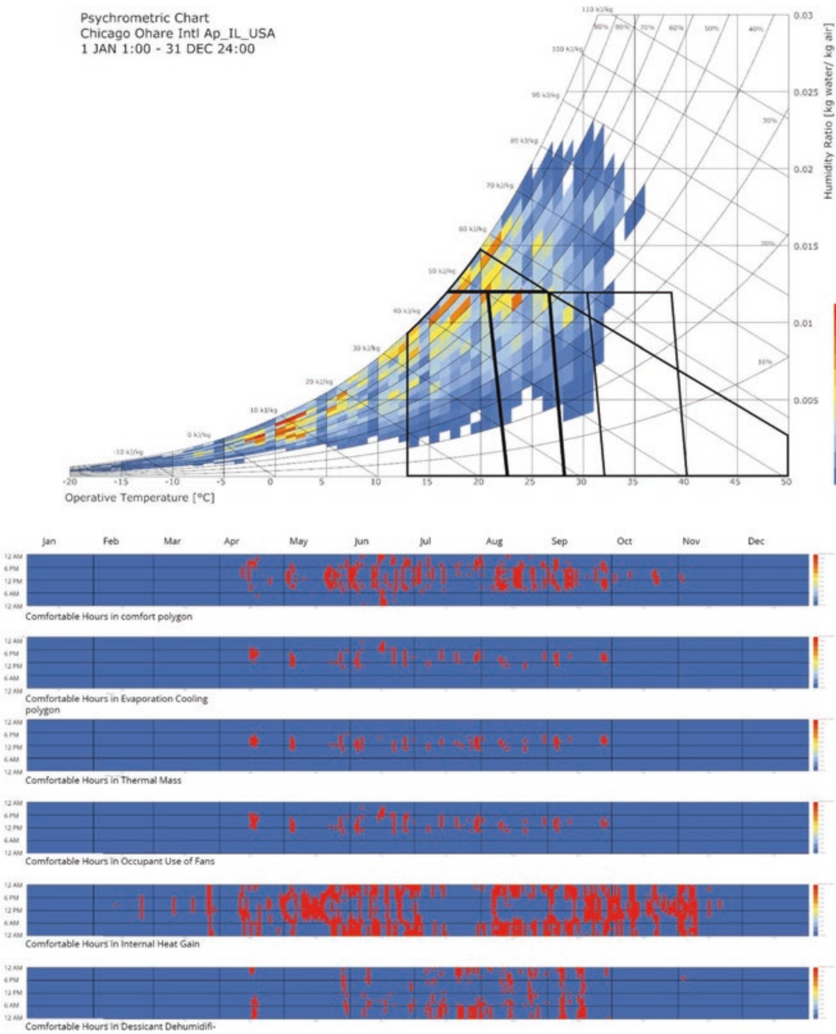

Fig. 44 (continued)

entire city block near the center of Michigan Avenue, the building serves not only as a restaurant but also as a public outdoor space. As there are no public parks within a one-third mile radius of the site, the McDonald's Flagship location provides necessary and usable space for the surrounding community. Considering the walkability and pedestrian-oriented nature of the building, it is no surprise that this design resulted in a 72% increase in pedestrian friendly spaces from the original design [59].

While many buildings that reach a net-zero or LEED Platinum status are designed from the ground-up, the McDonald's Flagship locations strategically utilize kitchen space and existing walls from the prior building into the final design. Ross Barney

Architects claimed that "The most sustainable building is one that is already built" [59]. Remaining in accordance with this quote, both the existing basement and kitchen of the previous building were retained and incorporated into the final building design. Existing walls were re-clad to improve thermal value and contribute to the sustainable status of the building. In addition to the reuse of existing materials, the McDonald's Flagship made history as the first commercial building in the city of Chicago to use timber as the primary structural material. Both CLT and glulam were chosen for their light environmental impact. This primary structural system, together with the additional use of steel, combine to form the 19,000 square feet structure [60]. Both timber and steel elements are visible from the interior of the building's dining area with 27 foot high ceilings, as illustrated in Fig. 45.

Possibly one of the most unique sustainable elements of the McDonald's Flagship is the inclusion of plants and green space in and around the building (Fig. 46). Compared to the prior structure, there is over 400% more green space in the final design [61]. Over 70 trees are placed on-site around the exterior of the building and over 10,500 plants in total [58]. The outdoor plants are situated near permeable outdoor paving that reduces storm-water runoff and minimizes irrigation. Inside the structure, floating glass walls of native ferns and white birch trees can be seen from the dining area. As shown in Fig. 47, a row of harvestable apple trees is even visible from the interior of the dining area. Rooftop trees and a rooftop garden also contribute to the inclusion of plants in the design. All produce grown on-site – including apples, arugula, broccoli, kale, Swiss chard, and carrots – are donated to the Ronald McDonald House [59]. The inclusion of these plants helps improve air quality and create an oasis in the center of Chicago.

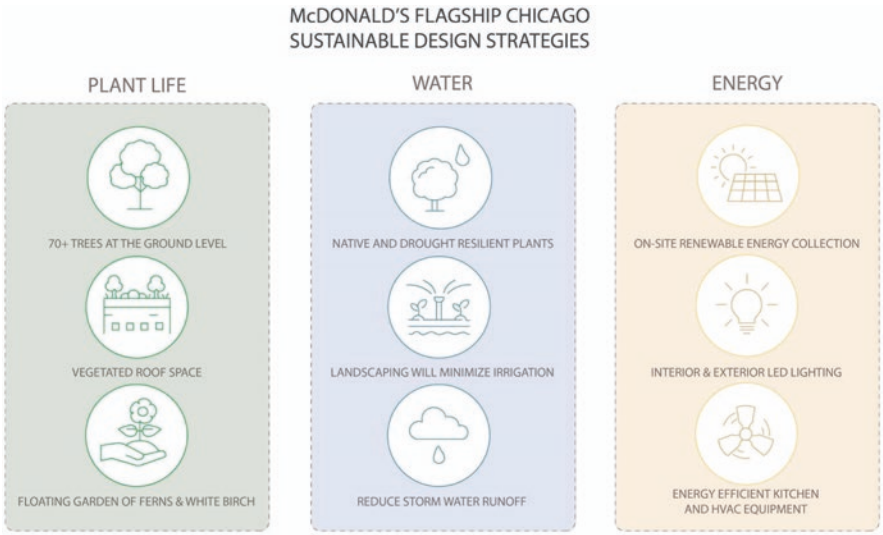

Fig. 45 Sustainable strategies. (Original diagram credit: https://corporate.mcdonalds.com/corpmcd/en-us/our-stories/article/ourstories.new_flagship.html)

Fig. 46 The McDonald's Flagship was the first commercial building in Chicago to use timber framing as a primary structural element. (Credit: David Thaddeus)

Envelope

The envelope of the Chicago McDonald's Flagship could be reasonably broken down into two main categories: the solar pergola and the structure underneath it. The solar pergola, often described as the "big roof," is supported by 12.75-inch diameter hollow structural section (HSS) columns [62]. Acting as both shading and energy-generating elements, the pergola consists of 1062 south-facing solar panels [59]. This large shading device hovers above the interior spaces below as well as the drive-through car line and is outperforming initial estimates modeled for energy generation, as shown in Fig. 48.

Fig. 47 "Floating" white birch and fern trees can be seen from the interior dining room. (Credit: David Thaddeus)

The second "envelope" that can be identified when analyzing the Chicago McDonald's Flagship building is the structure underneath the hovering pergola. A space of 12,720 square feet, more than half of the total area of the building, is a renovated space from the previous "Rock 'n Roll" McDonald's [58]. The materials here were kept in place and covered in a new concrete facade. In contrast to the opaque and heavy concrete used in the existing structure, much of the new restaurant is covered in glazing. This VS-1 vertical facade system curtain wall is unique in that the facade is held to the mullions without visually obtrusive bolts [63]. The slender design produces a sleek and clean appearance to the outdoors and vice versa.

Fig. 48 The solar pergola hovers over the car lane providing shade and generating energy. (Credit: David Thaddeus)

Then **McDonald's Rock 'n Roll. Chicago. (Credit: Caitphoto. Caitlin on Flickr) and** *Now* **McDonald's Flagship, Chicago. (Credit: David Thaddeus)**

As illustrated in Fig. 49, the CLT roof deck is left exposed from the underside and visible to customers. The CLT deck measures 7 inches in thickness at the hanging atrium and 12 inches thick in the dining area [58].

Fig. 49 A VS-1 vertical facade system curtain wall allows for natural light to enter interior spaces and views of the outdoors from the inside. (Credit: David Thaddeus)

Operational Versus Embodied Energy

The Chicago McDonald's Flagship location was awarded a LEED Platinum status due to the sustainable features implemented in the design. While much of the energy generation, specifically the solar pergola, may appear more visually distinctive to the customers at the location, the material selection and embodied energy in the materials used also greatly contribute to this status. As discussed above, the building is encompassed by a large solar pergola made up of over 1000 solar panels. This system generates enough energy to run approximately 60% of the building's use [58]. As illustrated in Fig. 50, the operational energy production involved in the

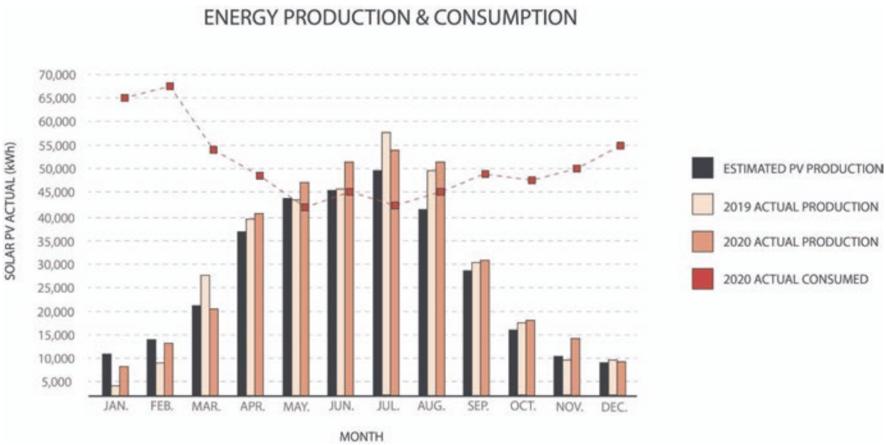

Fig. 50 Energy production and consumption. (Original diagram credit: https://acrobat.adobe.com/link/track?uri=urn%3Aaaid%3Ascds%3AUS%3A8aa2c8d4-d83e-4e65-969a-997bf2c1cd50#pageNum=1)

design saves McDonald's nearly 50% of the overall energy costs to run the restaurant [58]. Other operational energy systems include interior LED light fixtures with daylight sensors, smart exterior lighting that is designed to reduce light pollution in the city, and electric charging stations for customers. These techniques together help support the operational costs and use of the kitchen and central heating and cooling systems.

Although active techniques are included in the design to reduce operational costs and save energy, passive strategies, such as embodied energy due to the material selection, also play a key role in the sustainable design of the structure. Reuse of the previously existing structure in the new structure ensured that a smaller amount of new materials would be needed for construction. This eliminates the cradle-to-grave process involved in the creation of new materials for buildings. In this way, concrete was able to be reused in the building's structure with a smaller amount needing to be newly constructed. The concrete that was newly created utilized Carbon Cure Concrete, which sequesters recycled CO_2 into fresh concrete mix [58]. In the portion of the structure that was newly constructed, timber frame construction was used as the primary material selection (Fig. 47). It is estimated that the use of CLT in the building when compared to traditional construction methods equates to a saved carbon amount of 34,000 passenger vehicles off the road per year [58]. Not only does a natural and warm wood structure contribute to a more relaxed and inviting atmosphere, but it also contains a low embodied carbon footprint (Fig. 51).

The diagrams below display data obtained by using the ATHENA® Impact Estimator for Buildings. Located in Ontario, Canada, the ATHENA® Impact Estimator for Buildings was developed by the Sustainable Materials Institute. As part of the institute's mission, it leverages the life-cycle assessment in North America to promote sustainability in the built environment [59]. According to the

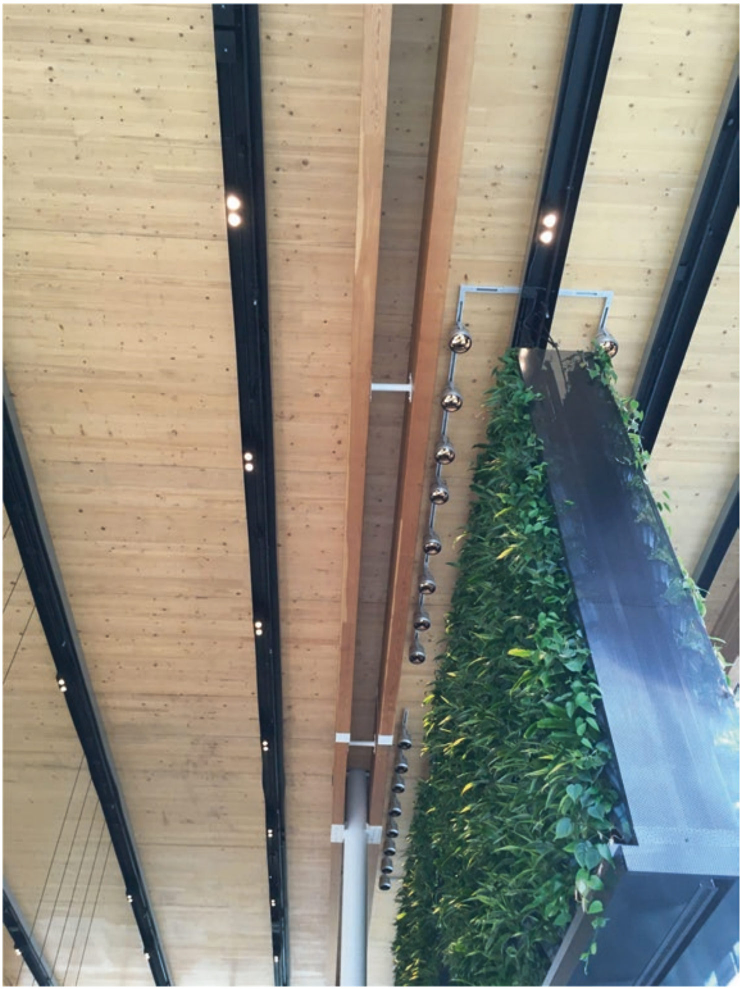

Fig. 51 Exposed timber roof deck elements can be seen from the interior dining area. (Credit: David Thaddeus)

developers, "robust life cycle inventory databases provide exact scientific cradle-to-grave information about building materials and products, transport, and construction and demolition activities" [63]. The Athena Institute connects designers to the power of life-cycle analysis without requiring them to become LCA experts themselves [63].

Any part of a building has the potential to be modeled using the Impact Estimator when the bill of materials has been provided. Using simple inputs, the Impact Estimator can create a bill of materials for users who do not have one. Examples include [54] foundations, footings, slabs, all below- and above-grade structure and envelope, windows and doors, and building interiors. Based on a 60-year life cycle, the study examines the overall building's life cycle. According to ISO 14040, we can compare up to five design scenarios according to the US Environmental Protection Agency's environmental impact categories [59]. In this study, the following environmental metrics were used: Global Warming Potential, Smog Potential, Acidification Potential, Non-Renewable Energy, Eutrophication Potential, and Ozone Depletion Potential. As inputs to the Impact Estimator, a series of factors related to the building are considered in order to calculate the life-cycle impact of each factor on the above categories. There are five assemblies that consist of information on the project: foundations, floors, columns and beams, roofs, and walls.

Any section of the building must be devoid of various types of materials and constructional elements. The Chicago McDonald's Flagship is mostly made up of CLT and wooden elements, while there are also steel columns and curtain walls. For any other elements that cannot be measured in one of the above assemblies, we can use the "Project extra materials" section. Regarding the operating energy consumption, based on the information provided by the design team, the amount of electricity in kWh per year was entered (Fig. 52).

The diagram shows the comparison between different constructional categories of the case study. In this chart, the highest CO_2 emissions are found in walls and roofs due to the widespread use of glazing and steel components (Fig. 53).

The diagram shows the comparison between different constructional categories of the case study. In this chart, the highest SO_2 emissions are found in walls and roofs due to the widespread use of glazing and steel components (Fig. 54).

The diagram shows the comparison between different constructional categories of the case study. Compared with previous charts, the highest concentrations of nitrogen (N) emissions are found in foundations, whereas in previous charts, it had less warming and acidification impact comparing walls and roofs. In part, this can be attributed to the use of concrete for foundations (Fig. 55).

The diagram shows the comparison between different constructional categories of the case study. It is interesting to note that concrete-made foundations have the

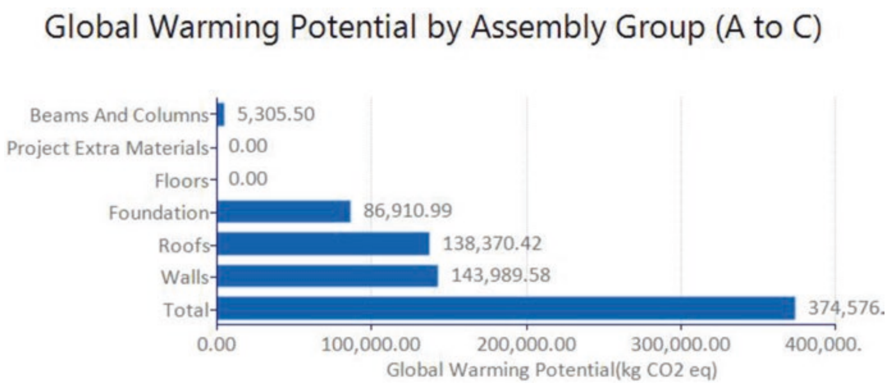

Fig. 52 Global warming potential. (McDonald's Flagship, Chicago)

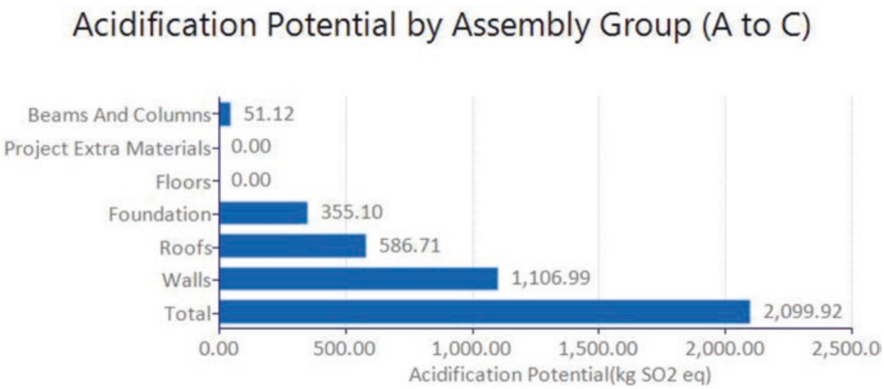

Fig. 53 Acidification potential (McDonald's Flagship, Chicago)

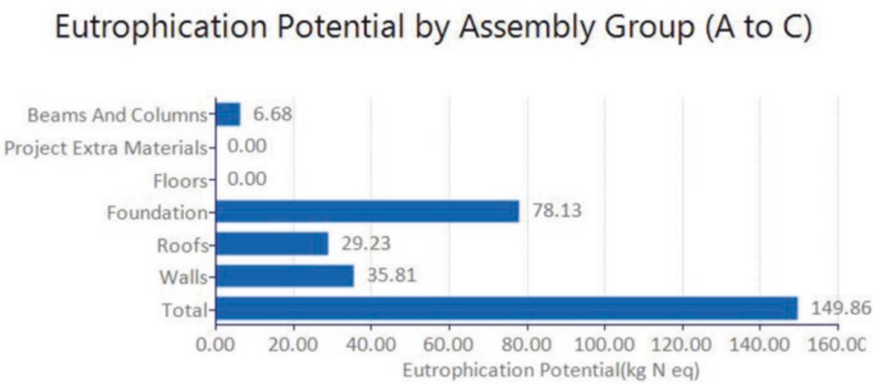

Fig. 54 Eutrophication potential (McDonald's Flagship, Chicago)

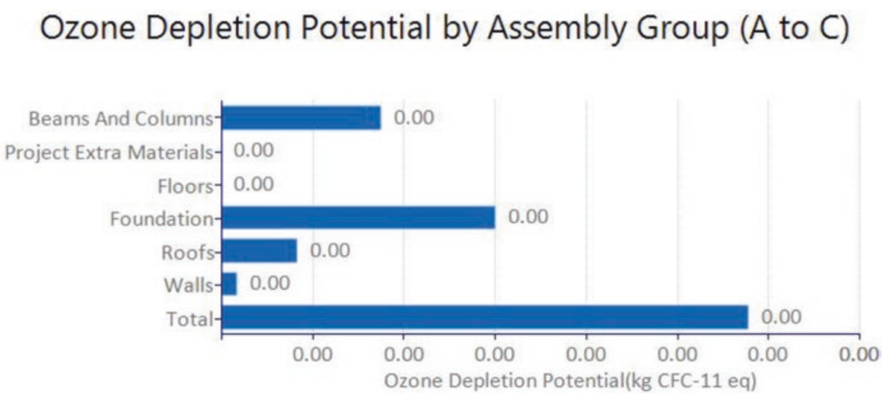

Fig. 55 Ozone depletion potential (McDonald's Flagship, Chicago)

most impact on CFC emissions, which again shows the negative impacts of using concrete even in small quantities (Fig. 56).

The diagram shows the comparison between different constructional categories of the case study (Fig. 57).

The diagram makes a comparison between operating and embodied global warming potentials (Fig. 58).

Figure 59 displays the comparison between different constructional categories that are used in the case study. The report compares the amount of CO_2 emissions that each section can have on the environment (Fig. 60).

The figure displays the comparison between different constructional categories that are used in the case study. The report compares the amount of O_3 emissions that each section can have on the environment (Fig. 61).

A comparison is made between operating and embodied in both primary energy and global warming potentials. Operating accounts for a greater share in both charts.

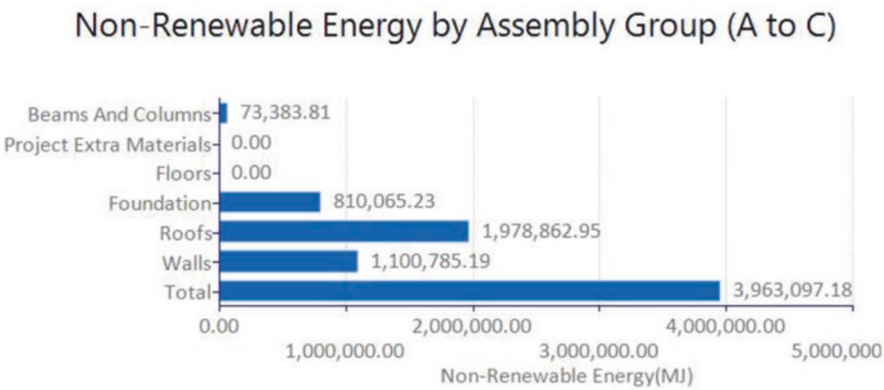

Fig. 56 Non-renewable energy (McDonald's Flagship, Chicago)

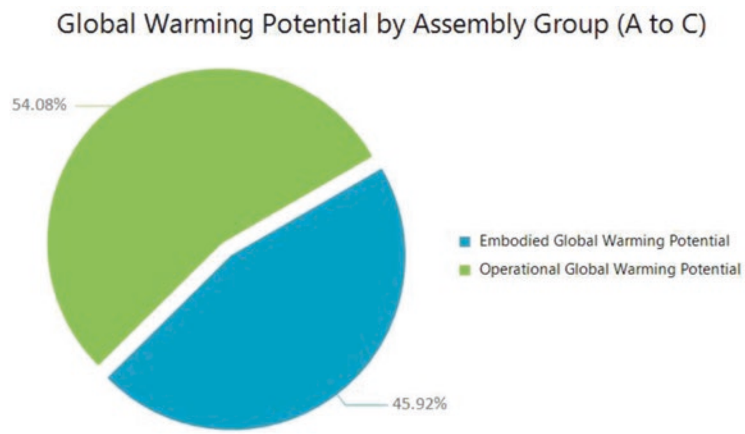

Fig. 57 Non-renewable energy (McDonald's Flagship, Chicago)

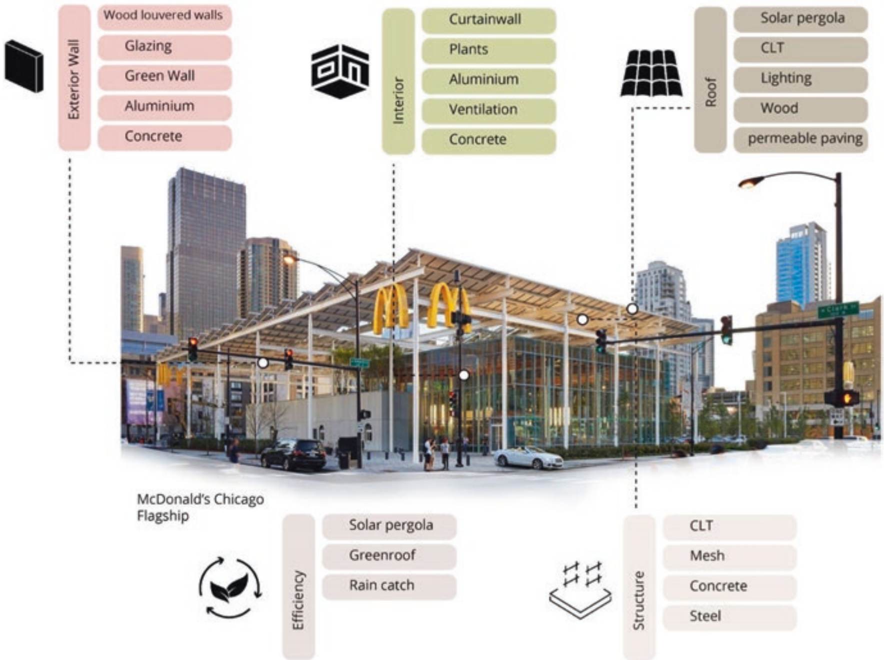

Fig. 58 Envelope materials and integrated sustainable strategies

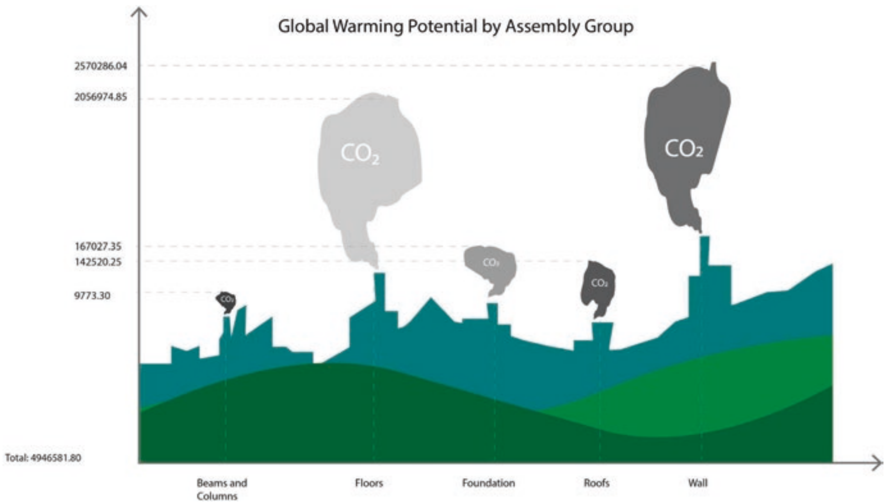

Fig. 59 Global warming potential

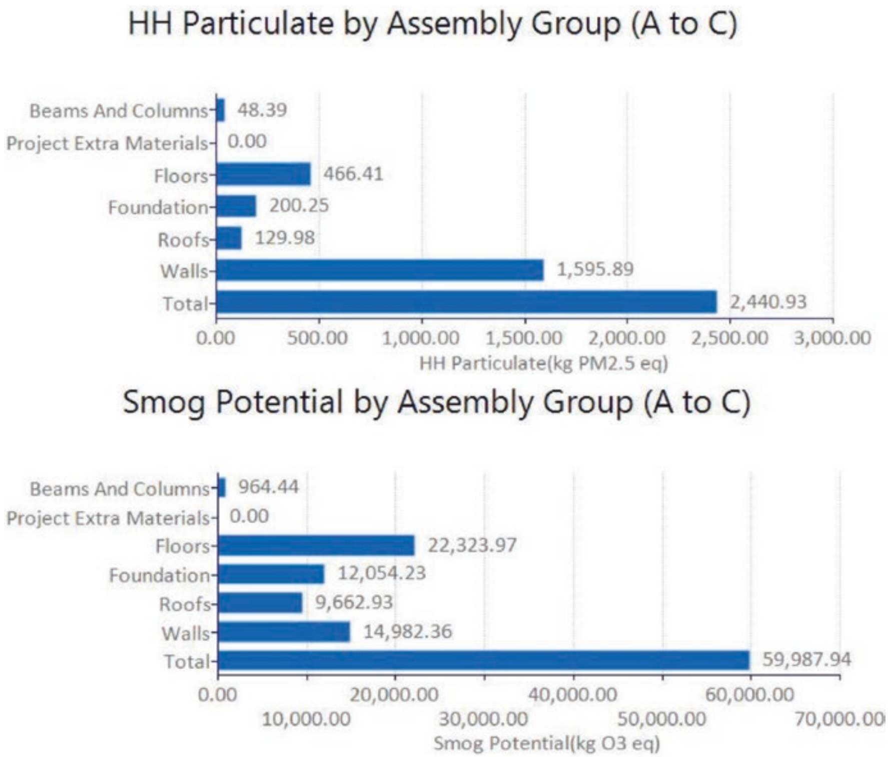

Fig. 60 Human health particulate and smog potential

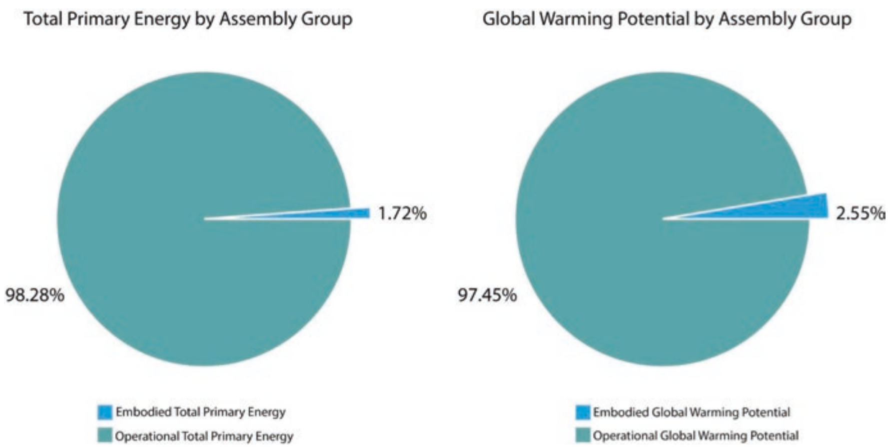

Fig. 61 Left: operational versus embodied energy; right: global warming potential

Conclusion

Since its completion in 2018, the Chicago McDonald's Flagship building has garnered a large amount of press and attention due to the sustainable features included. Both the passive and active strategies employed by Ross Barney Architects are the foundation for the LEED Platinum status and regard that the design holds. Most notably, the structure will forever serve as the first commercial use of CLT in the city of Chicago and has set a precedent for future McDonald Flagship locations. McDonald's calls the transformation of this building the "Experience of the Future" 'with the goal of enhancing customer experience dramatically [60]. At the time of construction, nearly 5000 McDonald's locations had been transformed to meet the "Experience of the Future" guidelines, although it can be argued that none have gained the recognition or utilized the vast amount of sustainable strategies that are in place at the Chicago McDonald's Flagship location.

Port of Portland Headquarters Building

Architect: ZGF

Introduction

Designed by ZGF and constructed in 2010, the Port of Portland Headquarters building is ranked by Forbes as one of the 10 most high-tech sustainable buildings in the world. The building is located in Portland, Oregon, and reacts to the Mediterranean climate of the region. Both a high-performance glazing system and a reflective roof membrane actively minimize heat gain from this climate. The building program includes seven floors of public airport parking and three floors of office space, totaling 205,603 square feet [64]. Awarded the Smart Environments Award by the International Interior Design Association and Metropolis magazine, the design reaches a LEED Platinum status. This writing aims to investigate both operational and embodied aspects of the design with specific attention to the envelope and its relationship to the overall sustainable status of the structure (Fig. 62).

Identified as a Mediterranean continental climate, Portland, Oregon, is characterized by short warm summers and overcast very cold winters. During December, Portland's cloudiest month, the sky is overcast nearly 75% of the time [65]. As a result, December is also the wettest month of the year with 6.8 inches of rainfall [66]. In contrast, Portland's dry season is in summer, and cold season generally lasts from October to March. Portland averages 43 inches of rain per year, 3 inches of snow per year, and well below the national average of sunny days per year [65]. The average temperature in Portland ranges from a high of 81 degrees Fahrenheit in summer to a low of 36 degrees Fahrenheit in winter [65]. With the help from the US

Fig. 62 Port of Portland Headquarters building. (https://inhabitat.com/green-roofed-port-of-portland-headquarters-aims-for-leed-gold/)

Department of Energy, the Passive Solar Industries council has set guidelines for climate-reactive passive strategies employed in the Portland region [67]. While this information is specifically targeted to residential homes, much of the climate combattant information can also relate to larger structures such as the Port of Portland Headquarters building. Some of these guidelines include increasing insulation and adding exposure to the sun from the south. It should be noted that the magnetic north in Portland is 21 degrees of true north and should be corrected when considering light exposure (Fig. 63).

Sustainable Features

While the form, being influenced by the shape of an airplane hull, is striking in itself, it is the sustainable features included in the design of the Port of Portland Headquarters building that has garnered attention from the public, which defines it as a noteworthy case study. The sustainable features of the structure expand beyond the building itself and are present in the site. Constructed wetlands on-site include both tidal and vertical flow wetland cells. Filled with native, naturalized, and flowering plants that avoid attracting birds in close proximity to the airport, these wetlands additionally aid in the wastewater treatment [68]. Coined as a "Living Machine," the wastewater system is located in the interior lobby to serve a percent for the possibilities of such technology, as illustrated in Fig. 64.

Occupying a total of 700 square feet indoors, the system additionally utilizes the outdoor wetlands to cycle water [70]. Compared to a similar structure of the same size, the Port of Portland Headquarters building decreases water use by 75% from the baseline due to the efficient water features, as shown in Fig. 65 [70]. An

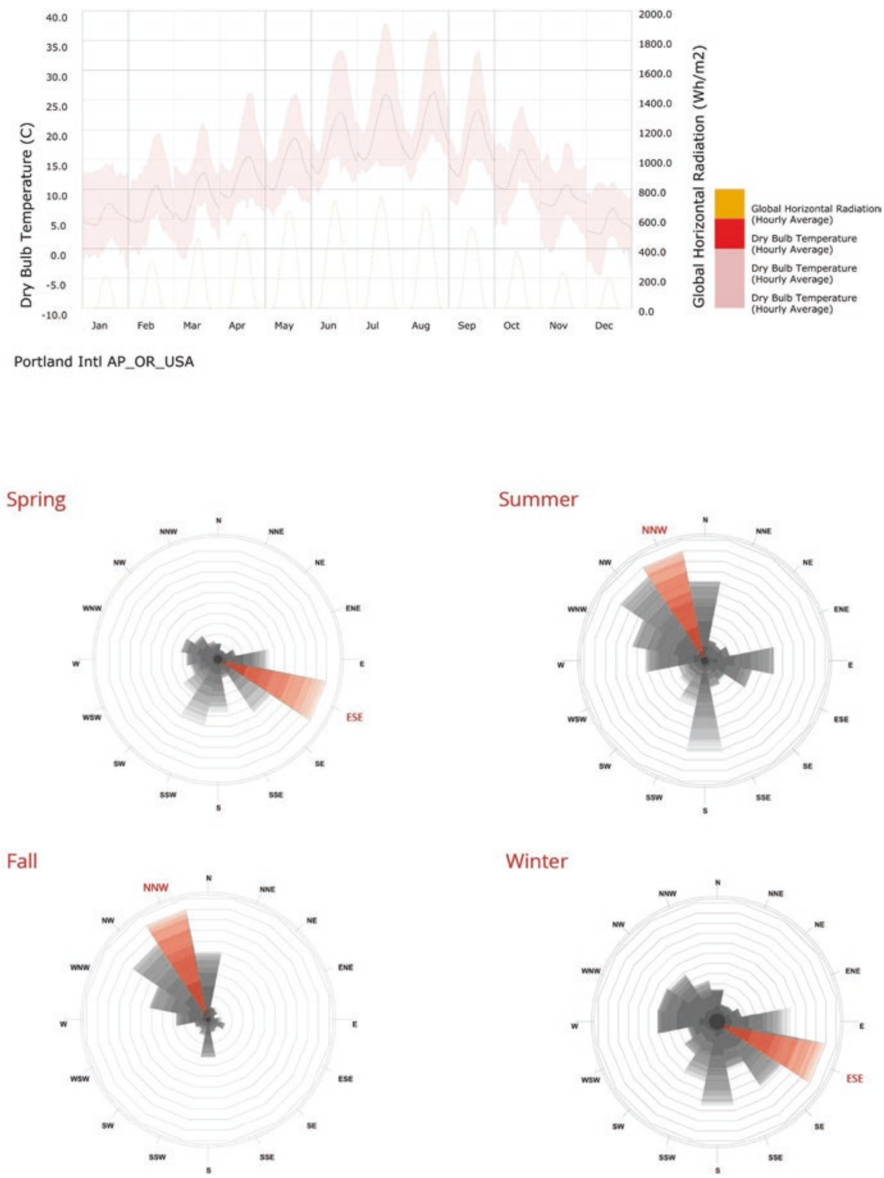

Fig. 63 Climatic data, dry-bulb temperature, wind roses, and psychrometric chart

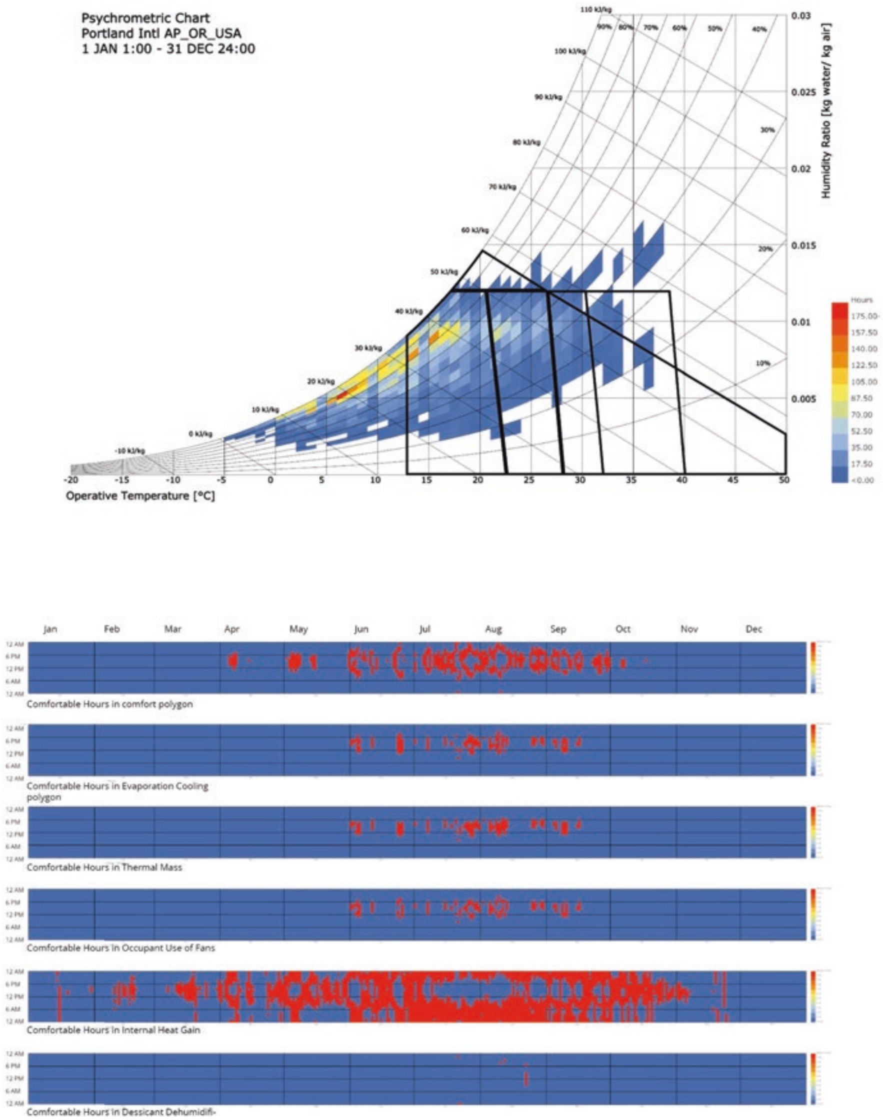

Fig. 44 (continued)

ecological wastewater treatment system, the Living Machine system produces quality fresh water from both gray and black water without odors, chemicals, offensive by-products, or high-energy usage typical of conventional systems [71]. In their tidal flow cells, the Living Machine uses many plants to decontaminate incoming wastewater at levels far exceeding the Oregon Department of Environmental Quality's standards. An additional benefit is that the plants enhance the overall beauty of the site and create a microclimate within and around the building [69].

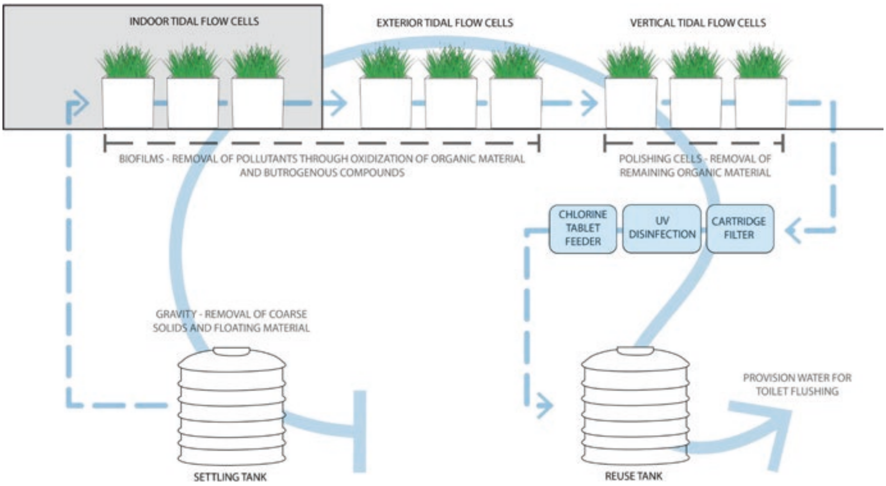

Fig. 64 Living Machine [69]

Fig. 65 The "Living Machine" mimics an interior garden while working to cycle wastewater. (https://www.mayerreed.com/portfolio/port-of-portland-headquarters-parking-garage/)

Above ground and located on the 9th floor of the structure is an extensive green roof amounting to a total of 10,000 square feet, as illustrated in Fig. 66 [70]. Additionally, helping to treat rainwater, this green roof aids in insulating the building and reducing the heat island effect. Other sustainable features included in the design of the Port of Portland Headquarters building include a high-performance glazing system utilized on the exterior of the building.

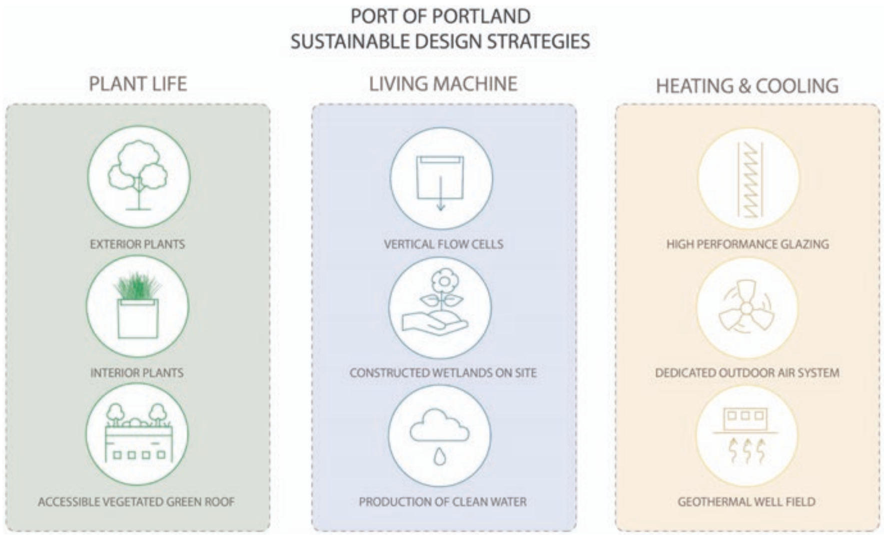

Fig. 66 Sustainable strategies

Envelope

The Port of Portland Headquarters building features a reflective roof membrane and high-performance glazing to minimize heat gain and energy consumption. An extensive eco-roof covers the roof of the 9th floor of the building, which reduces the heat island effect and offers a large surface area for rainwater treatment. Treatment of wastewater is assisted by a Tidal Flow Wetland Living Machine [72]. In addition to the high-performance glazing utilized, sensors are used for maintaining efficient and sustainable occupant comfort levels. By placing sensors and taking advantage of sidelight from windows, the lighting design is optimized. Light and occupancy sensors are included with each fixture as part of the control system in the open office [72]. In order to balance and control daylight, glare, and heat gain, automated exterior shades and light shelves were utilized. Workstations are also equipped with task lighting to reduce the need for overhead lighting [72], as shown in Fig. 67.

Operational Versus Embodied Energy

The Port of Portland Headquarters building utilizes efficient and high-tech solutions to energy generation and utilization. Below ground, 200 geothermal wells aid in managing heating and cooling [73]. The design for air inside the building consists of a dedicated outdoor air system (DOAS) that works in conjunction with the geothermal wells below ground as well as a radiant ceiling system consisting of over

Fig. 67 Green roof. (https://inhabitat.com/green-roofed-port-of-portland-headquarters-aims-for-leed-gold/)

56,000 square feet of metal radiant ceiling panels [72]. The building's plan is primarily an open layout with shared offices divided by half-walls and does utilize an RCP system with underfloor ventilation. A traditional forced-air system, which is used throughout the rest of the building, provides the air conditioning for the smaller, contained break-out and meeting areas [74].

When compared to the average office energy use intensity (EUI) performance from the national CBECS 4 and California CEUS 5 datasets, the Port of Portland Headquarters building shows a drastic reduction of over 40% [75]. The total EUI currently amounts to 46 kBtu/ft^2. When compared to an office building built to the Oregon code 2010, it can be seen that the building uses 30% less energy than a traditional office structure. Although much lower in energy use than traditional office buildings, it should be noted that the Port of Portland Headquarters building uses 15% more energy than the ASHRAE best-practice energy efficiency standard 100 [75]. In addition to energy use, the Port of Portland Headquarters building also shows higher rates of occupant thermal comfort when compared to the baseline. As illustrated in Fig. 68, it should be noted here that a few zones of the Port of Portland Headquarters building have override controls for window blinds and thermostats that residents are given remote access to [74]. Along with the sensor technology, these contribute to efficient occupant comfort levels.

The diagrams below display data obtained by using the ATHENA® Impact Estimator for Buildings. Located in Ontario, Canada, the ATHENA® Impact

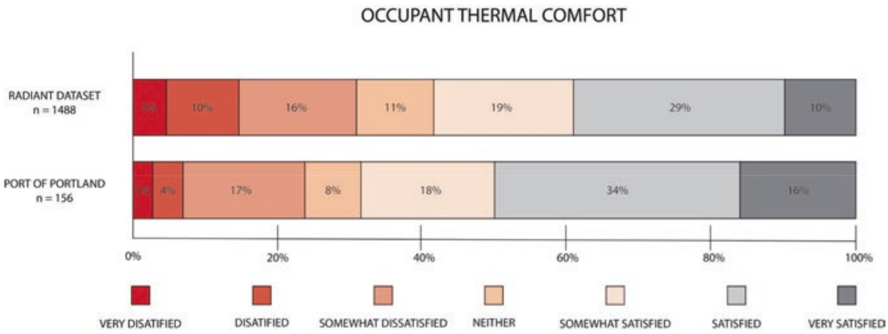

Fig. 68 Occupant comfort levels. (Original diagram credit: Caroline Karmann https://escholarship.org/content/qt3cj9n3n4/qt3cj9n3n4_noSplash_22165b8afc25e451d393ae2571822695.pdf)

Estimator for Buildings was developed by the Sustainable Materials Institute. As part of the institute's mission, it leverages the life-cycle Assessment in North America to promote sustainability in the built environment [68]. According to the developers, "robust life cycle inventory databases provide exact scientific cradle-to-grave information about building materials and products, transport, and construction and demolition activities" [69]. The Athena Institute connects designers to the power of life-cycle analysis without requiring them to become LCA experts themselves [69].

Any part of a building has the potential to be modeled using the Impact Estimator when the bill of materials has been provided. Using simple inputs, the Impact Estimator can create a bill of materials for users who do not have one. Examples include [65] foundations, footings, slabs, all below- and above-grade structure and envelope, windows and doors, and building interiors. Based on a 60-year life cycle, the study examines the overall building's life cycle. According to ISO 14040, we can compare up to five design scenarios according to the US Environmental Protection Agency's environmental impact categories [68]. In this study, the following environmental metrics were used: Global Warming Potential, Smog Potential, Acidification Potential, Non-Renewable Energy, Eutrophication Potential, and Ozone Depletion Potential. As inputs to the Impact Estimator, a series of factors related to the building are considered in order to calculate the life-cycle impact of each factor on the above categories. There are five assemblies that consist of information on the project: foundations, floors, columns and beams, roofs, and walls (Fig. 69).

Figure 70 displays the comparison between different constructional categories that are used in the case study. The report compares the amount of CO_2 emissions that each section can have on the environment.

A comparison is made between operating and embodied in both primary energy and global warming potentials. Operating accounts for a greater share in both charts (Fig. 71).

Figure 72 displays the comparison between different constructional categories that are used in the case study. The report compares the amount of O_3 emissions that each section can have on the environment.

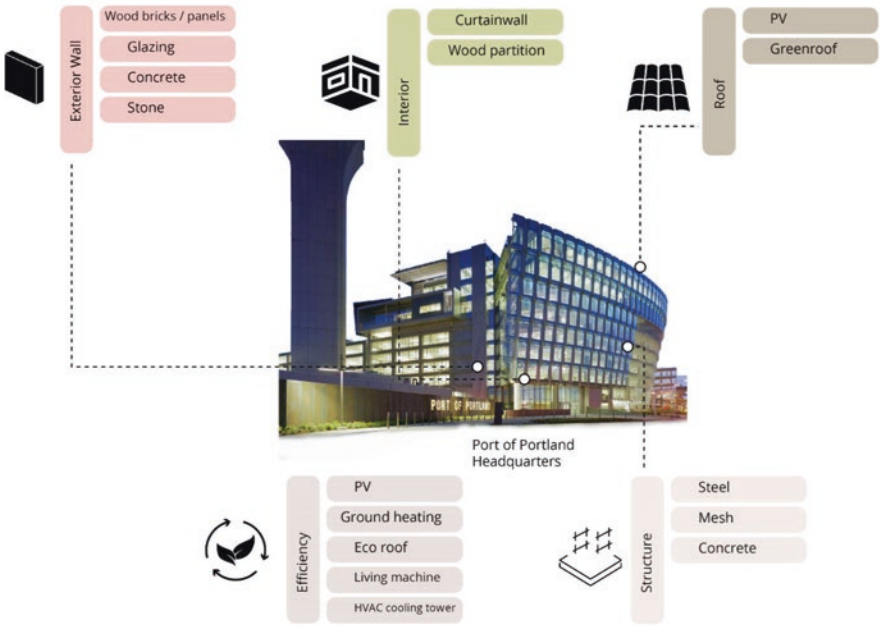

Fig. 69 Envelope materials and integrated sustainable strategies

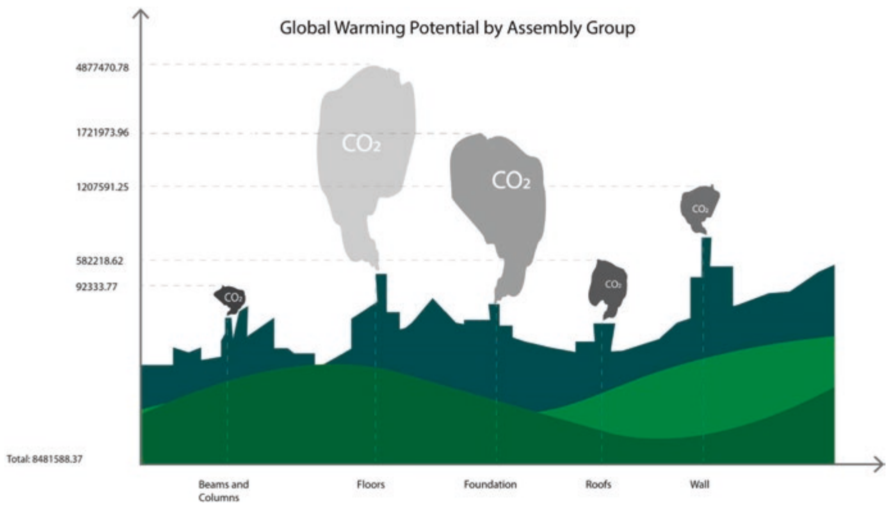

Fig. 70 Global warming potential

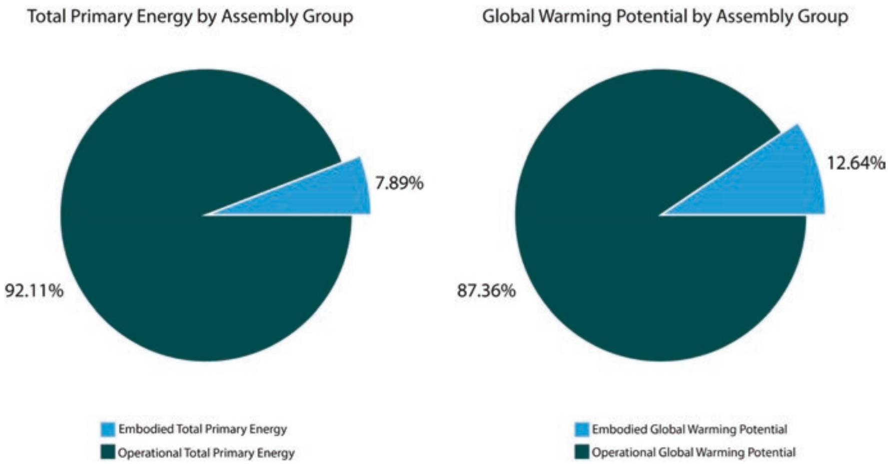

Fig. 71 Left: operational versus embodied energy; right: global warming potential

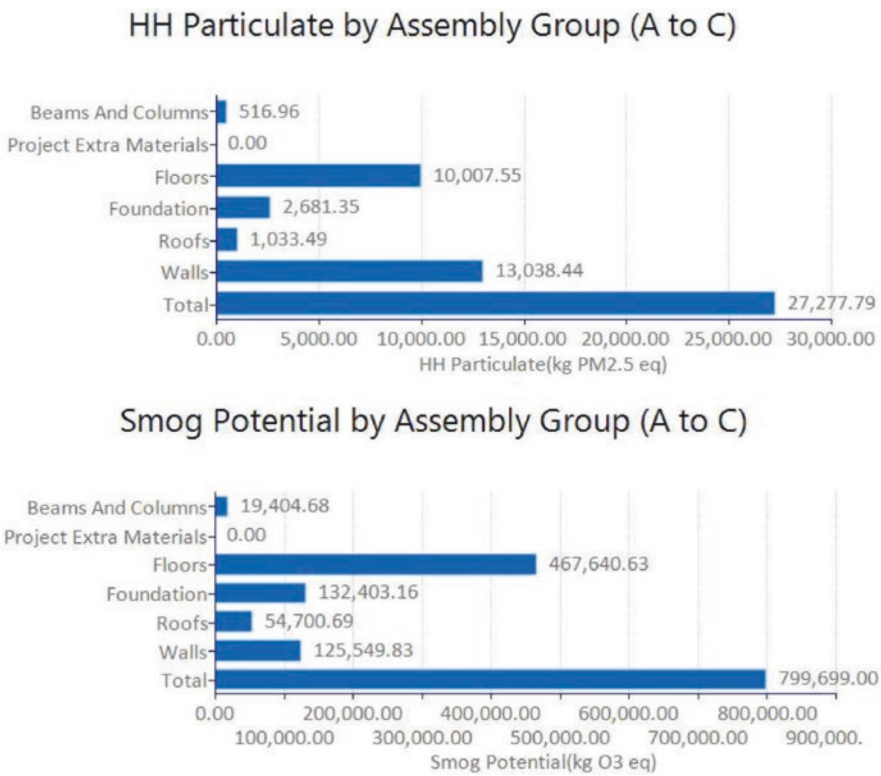

Fig. 72 Human health particulate and smog potential

Conclusion

The Port of Portland Headquarters building reacts to the Mediterranean climate of the region through both passive and active techniques that contribute to the design's label as a LEED Platinum building. Most notably, the sustainable features of the structure expand beyond the building itself and are present in the site as represented through the complex living machine. Due in part to the green roof, PV energy generation, and geothermal wells, the building uses 30% less energy than a traditional comparable office building. These statistics, combined with the ingenuity of the design, mark the Port of Portland Headquarters as a prime example of sustainable design in the USA.

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