Constructing a Green Campus with the Living Building Challenge

Integrated Concentration in Science

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1. Executive Summary

As the Carbon Mitigation Task Force determines strategies to create a decarbonized and 100% renewable campus, the task of decreasing the impact of buildings on campus energy use is paramount in this effort. A majority of the energy on campus is used to heat, cool, and support buildings. To reduce building energy use, new construction projects and major renovations are required to achieve a Silver rating or higher on the Leadership in Energy and Environmental Design (LEED) standard. Despite decreases in campus emissions over the last decade, the University is still not on track for carbon neutrality by 2030.

The magnitude of the challenge necessitates reenvisioning the campus infrastructure development process. Mandating LEED Silver has not resulted in the emissions reductions needed to achieve carbon neutrality. A new Green Building Guideline is needed to bring UMass to a net-zero carbon future. The Living Building Challenge (LBC), which is a design philosophy and building criteria with an emphasis on achieving net-positive energy buildings, can become that Green Building Guideline for UMass. The energy strategy of the LBC is simple: minimize the energy needs of a building, then meet the remaining need with renewable energy.

Expanding campus with Living Buildings will result in no increase of annual carbon emissions and renovating the existing building stock will decrease campus emissions towards neutrality. Projects will create opportunities for students and faculty to offer their own expertise on zero energy buildings, furthering the research and educational mission of the campus. By implementing the Living Building Challenge for all future buildings and renovations, UMass can achieve carbon neutrality through net-zero energy buildings.

2. Introduction

As the largest state-owned emitter of greenhouse gases in Massachusetts, the University of Massachusetts Amherst has a responsibility to find ways to reduce its impact on the environment. The University's public commitment to mitigating its emissions and achieving carbon neutrality is offering the campus community an opportunity to engage with this challenge and propose creative solutions. Our team is composed of students in the Integrated Concentration in Science (iCons) program. By incorporating our unique academic backgrounds, research, and excitement for addressing global challenges, we have found that shifting building standards towards the Living Building Challenge (LBC) by prioritizing net-zero energy use will be most effective at mitigating campus emissions.

Currently, the UMass Green Building Guidelines adhere to the LEED rating system to reduce the environmental impact of buildings on campus [1]. LEED rates aspects of building design, construction, operation, and maintenance with the intent of reducing emissions, energy use, and potable water use [2]. A study of LEED buildings found minimal correlation between LEED certification level (Silver, Gold, etc.) and energy use intensity, a measure of energy efficiency. This indicates that the LEED rating system may not be useful for mitigating greenhouse gas emissions. Based on a 2004 baseline, UMass' efforts to reduce emissions, including implementing LEED, have only resulted in a 25% reduction in FY19, short of the 40% goal by FY20 [3]. LBC offers a path to carbon neutrality that is closely aligned with UMass' goals with its emphasis on net-zero energy use.

Constructing net-zero energy Living Buildings at UMass will require institutional and academic collaboration. Professionals in the Architecture, Building and Construction Technology, and Landscape and Regional Planning departments with experience in green construction must collaborate with Campus Planning, Physical Plant, and external firms. This combination of expertise will allow UMass to incorporate cutting-edge technologies into new construction and renovation projects to greatly reduce the campus' overall energy usage. Reducing campus energy use is our main strategy for reaching the 2030 net-zero carbon goal.

Revising building standards is not only effective but necessary to achieve carbon neutrality, given that most of UMass' energy goes toward building uses [3]. Importantly, LBC principles are also applicable to renovations of existing buildings. Although renovated buildings may face more challenges in achieving full Living Building status, applying energy-use reduction methods will assist the campus in reducing carbon emissions. Implementing LBC guidelines for future campus buildings and renovations will result in enormous reductions in overall energy usage and carbon emissions.

3. Problem Statement: The Shortcomings of LEED

When considering why it is important for UMass to shift from LEED to LBC guidelines, it is crucial to evaluate the current LEED-based Green Building Guidelines. LEED certifications are not based on actual building energy outcomes, but rather on a list of practices that may be associated with decreased energy use in a building. LEED's point ranking system considers the following categories: sustainable siting of the building, water use efficiency, energy and atmosphere, materials and resources, and indoor environmental quality [4]. Within each category, the LEED system requires certain baseline building features and allows for additional optional credits. LEED awards Certified, Bronze, Silver, Gold, and Platinum ratings depending on the number of optional credits completed. In accordance with Executive Order 484, UMass requires all new buildings and renovations to be rated LEED Silver or higher [5]. Despite this action, UMass' current carbon emissions statistics are not on track to reach carbon neutrality by 2030.

Thirteen years after the signing of Executive Order 484, UMass has exhibited only modest declines in greenhouse gas emissions. Using an average of 2002-2004 as the baseline, campus emissions were expected to reduce by 40% by the end of 2020 [3, 6]. However, there was only a 25% reduction exhibited in FY19. This reduction was largely due to the transition away from burning coal towards natural gas at the Central Heating Plant. Only about half of these reductions represented improvements in building efficiency through renovations [7]. Adhering to LEED Silver has not resulted in significant reductions in emissions associated with building energy use.

The idea that LEED certified buildings are "greener" than non-LEED certified buildings is highly contested. A widely-cited 2008 study, funded by the organization that publishes the LEED standards, concluded that LEED buildings on average use about 25-30% less energy than other buildings [4]. These calculations were based on a voluntarily submitted dataset and compared overall energy usage of buildings. When considering Energy Use Intensity (EUI), or energy usage per square foot, the same dataset indicated that **many of the reported LEED buildings had higher EUIs** than a comparable conventional building [4]. Additionally, the original study compared median energy use data from LEED certified buildings with the mean energy use from non-LEED certified buildings. Since these two measures cannot be compared, the conclusion drawn is rendered inappropriate [8]. Globally, institutions have conflated LEED and energy efficiency to signify their nominal commitment to sustainability. UMass must place greater emphasis on actual energy performance rather than achieving LEED certification to significantly reduce carbon emissions.

Although the average LEED building has a lower EUI than a non-certified building, many LEED-certified buildings often consume more energy per square foot. Between 28% and 35% of LEED buildings use more energy than a conventional building of comparable size per square foot [4]. Figure 1 demonstrates a weak correlation between a building's LEED ranking and its EUI, meaning a high-ranking LEED Platinum building can consume more energy than a LEED Silver building [8]. If there were a strong correlation between LEED certification and EUI, then the colors in Figure 1 would be binned in groups of the same LEED ranking, with LEED Platinum buildings exhibiting the lowest EUIs. That is not the case, as Figure 1 shows more of a random pattern of EUI and LEED certification level. These post-occupancy energy use data suggest that further certification within LEED does not guarantee energy efficiency. These data also suggest that moving past a reliance on LEED guidelines is critical to getting to netzero carbon.

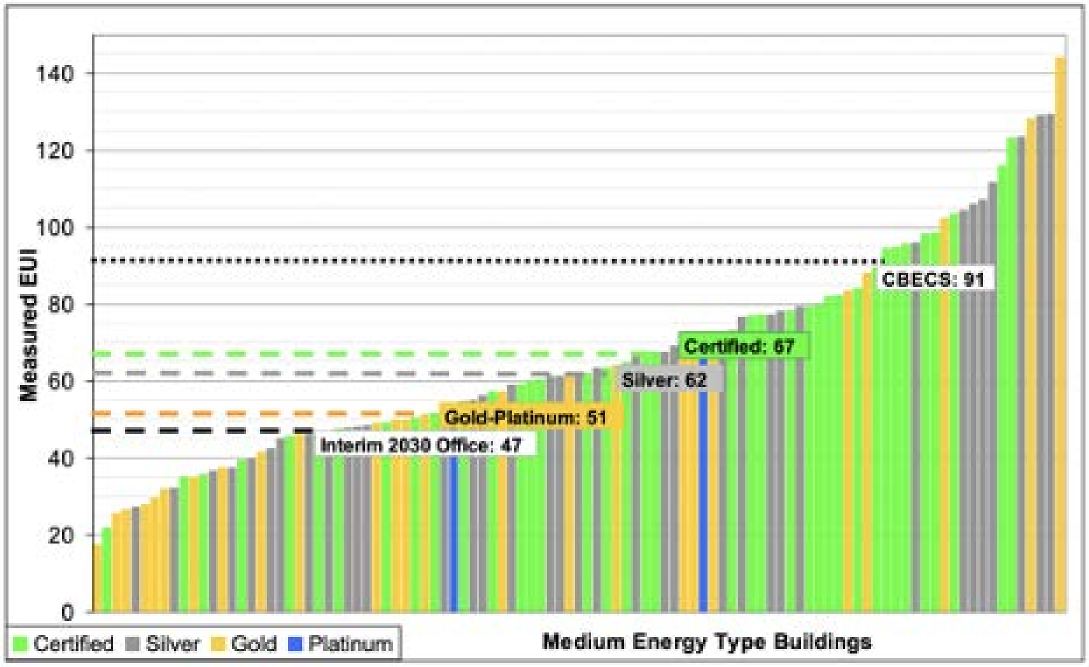

Figure 1: *Energy use intensity (EUI) of individual LEED certified projects, where the CBECS value is a national average EUI compiled by the federal Energy Information Administration [9]*

UMass cannot expect to reduce overall campus energy consumption while continuing to adhere to LEED standards. UMass Campus Planning recognizes that “the required LEED Silver certification for new buildings will not be enough to help the university meet the campus carbon neutrality goal for 2050” [1]. As a proposed alternative building standard, the Living Building Challenge (LBC) facilitates sustainable practices before, during, and after construction [10]. The LBC is a divergence from the more traditional LEED guidelines because it requires an integrated process from design inception to construction completion. Furthermore, energy use modeling must be analyzed at every step of the design and construction process to ensure that each decision improves energy performance. This focused design process creates actual reductions in buildings’ energy use that the current LEED guidelines often fail to achieve.

4. Solution Technology: Living Building Challenge Requirements

As UMass expands, LBC guidelines propose important infrastructure considerations. LBC is encapsulated by seven Petals: Place, Water, Energy, Health & Happiness, Materials, Equity, and Beauty. Petals have broad “Imperatives” (minimum requirements) to meet before, during, and after construction.

The Imperatives of the Energy Petal are the most relevant to reaching UMass’ carbon mitigation goals. Projects must achieve a reduction in total energy consumption when compared to a conventional building of comparable size (70% for new construction and 50% for renovations) and provide 105% of their energy usage through on-site renewable energy sources [11].

Achieving Living Building status depends on an integrated design process involving components of passive energy use reduction methods, active energy conservation methods, and renewable energy generation. Passive methods are foundational in reducing a building's energy use, propelling buildings on the path to become Living Buildings. These include the shape and orientation of the building in order to maximize sun exposure, well insulated walls and windows, and the intentional placement of windows to maximize daylight while minimizing heat loss. These passive methods require consideration in the early design process, as they involve the foundational elements of any design. Passive strategies typically present few additional costs to construction and enable the effective integration of other energy reduction elements later in the design process.

Many Living Buildings feature highly efficient building envelopes to reduce building heating and cooling loads. The envelope refers to the walls, roof, and windows of a building. The R.W. Kern Center, a Living Building at Hampshire College, has extra-thick walls and a roof that are filled with cellulose. This design increases the building’s wall and roof thermal efficiency to double the requirements of local building codes [11]. Cellulose is a better insulating fill material than traditional fiberglass because of its slightly higher insulating potential, minimal toxicity, and higher flame resistivity due to the lack of air circulation [12]. Thermal resistance, which represents the ratio of temperature difference between the material’s two faces to the rate of heat flow, is a good indicator of window efficiency. With a double-studded, cellulose-insulated 12-inch thick wall, the Kern Center achieves a high wall thermal resistance value of R-36 [11]. Standard single-paned windows have thermal resistances of around R-1, while triple-paned windows are around R-4 [13]. R values are linearly related; therefore, an R-36 wall is 9 times more efficient than an R-4 window. By combining thermally insulating walls with a low window-to-wall ratio, the Kern Center has a building envelope that significantly reduces the need for heating and cooling.

Starting with passive methods in the design process enables maximum effectiveness of active methods of energy conservation. Active methods often include efficient lighting and technologies, occupancy sensors, and radiant panels for heating. These methods are more costly to implement than passive but are crucial in reducing the energy use of a Living Building.

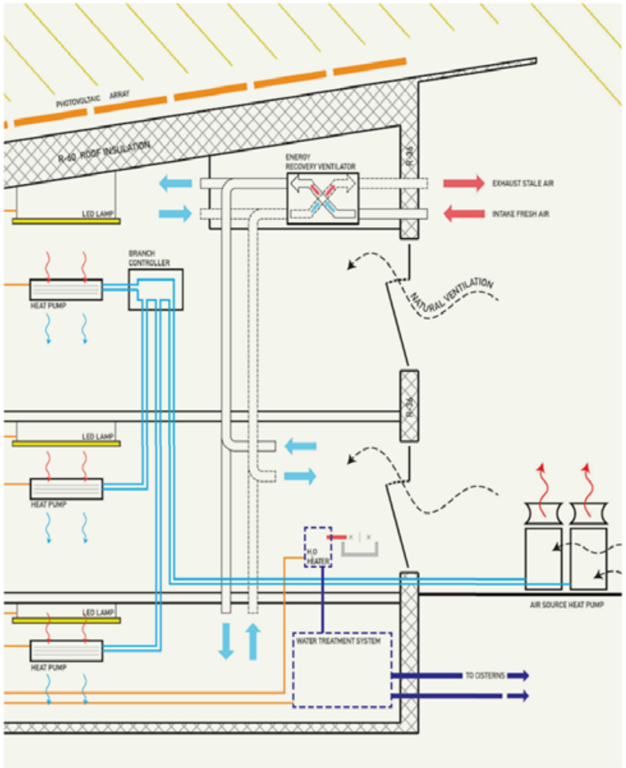

Figure 2. The R.W. Kern Center uses a central water heating system, and a heat exchange between incoming fresh air and outgoing stale air [11].

LBC requires that buildings provide sufficient ventilation [11]. To maintain a comfortable indoor environment, the R.W Kern Center has a separate air circulation system to account for its airtight seal. This allows fresh air to circulate without having to significantly heat or cool the new air to building temperature. As seen in Figure 2, the heat exchange system allows the building to bring in fresh air without losing indoor thermal energy.

After utilizing passive and active methods, renewable energy sources generate the remaining energy use of the building. Renewable sources include solar panels, geothermal heating/cooling, and vertical axis wind power generation. These methods are the most expensive; however, implementation after passive and active methods of energy-use reduction are essential for meeting the energy needs of many buildings.

For tall and skinny buildings, the reduced ratio between roof area and total-internal-building area makes it more challenging to meet energy demands through renewable energy sources due to limited solar potential. In these situations, a combination of renewable energy sources is necessary to supplement for the remainder of energy usage after minimizing the building's energy load as much as possible.

By minimizing the energy load from heating, air conditioning, and other sources, it becomes possible to meet 105% of a building's energy use with renewable sources. For example, in its first year of operation, the Bullitt Center, a six-story office building in Seattle, produced 172% of its energy use through building design efficiencies and a combination of solar and geothermal energy [14-15]. Achieving high-performance designs starts in the early stages of the design process, and energy modeling and analysis must happen at every step. To significantly reduce emissions, these principles must be applied to buildings at UMass for both new construction projects and renovations.

5. Implementation Plan: Achieving Living Buildings at UMass

Reshaping the Green Building Guidelines to incorporate Living Building Challenge requirements will propel UMass in reaching the goal of net-zero carbon emissions. Figure 3 depicts possible energy outcomes assuming a construction rate of 25,000 square feet per year. This assumption is modest, considering current construction is about 45,000 square feet per year. Recognizing the many use cases of future buildings, the average annual EUI is assumed to be approximately 100 kBTU per square foot. The projections consider three potential outcomes.

The red line depicts projected campus energy use following the existing Green Building Guidelines, based on recent EUI trends. This outcome results in an increase in building energy use at UMass as campus continues to expand. The yellow line depicts energy use if the Living Building Challenge were adopted for all new construction at UMass. Though this option does not significantly reduce the emissions of current buildings, no increase in building energy use is projected.

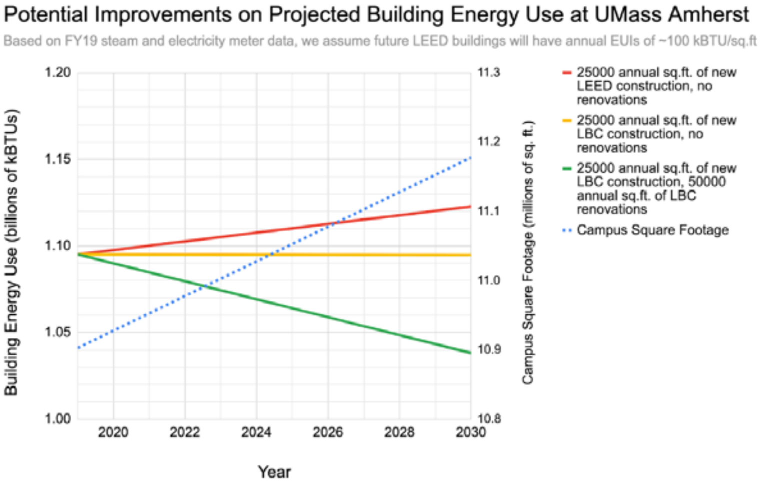

***Figure 3**. Three possible outcomes of UMass building energy use:*
1) Campus expansion using the current GBG
2) Campus expansion after transitioning to LBC
3) Using LBC for both future construction and renovation [20].

The final scenario, illustrated by the green line, assumes that UMass adopts the Living Building Challenge for renovations in addition to future construction. A renovation rate of 50,000 square feet per year is based on that of the Student Union. This outcome shows a significant decrease in overall building energy use on campus. For this reason, the final scenario is recommended to both reduce the impact of existing buildings and eliminate future emissions.

The following are recommendations for how to implement LBC guidelines at UMass Amherst based on existing buildings on campus. These recommendations will cover both the Integrative Learning Center (ILC), if it were built according to LBC standards, and the W.E.B. Du Bois library, where energy-reducing retrofits would greatly aid in energy efficiency.

Integrative Learning Center

In this example, the ILC is envisioned as if it were built to LBC requirements. This illustrates an application of a high ratio of roof solar potential to total building area. This is not a proposal for renovating the ILC, but an example of optimal energy efficiency had the ILC been constructed using LBC guidelines. We recommend that other UMass buildings like the ILC be built according to LBC standards.

The ILC has a high potential for energy efficiency that could have been optimized if LBC principles had been applied in the design process. The ILC stands at 4 stories tall with 173,000 square feet of classrooms, offices, auditoriums, and gathering spaces [16]. This provides a fairly high ratio of roof space to building area, which is ideal for harnessing solar energy. Utilizing photovoltaics on the roof would have capitalized on the building's solar potential. The ILC has a high window-to-wall ratio, meaning that there are many windows on the facade. Floor-to-ceiling windows create issues with thermal insulation and optical comfort. Since glass is more transparent and thinner in comparison to walls, glass is less thermally insulating. Walls can be further insulated with different fill materials, which increases their insulation compared to windows. Implementing a more efficient facade with more walls than windows will create fewer opportunities for thermal energy loss.

The central location of the ILC on campus requires that energy generation happens within the bounds of the building, given that the surrounding area is fully developed. The building has a 15,000 sq.ft. green roof, leaving 30,000 sq.ft. of unused roof space with potential for solar power generation. Utilizing solar panels on all 45,000 sq.ft. of the ILC's roof would produce about 769,500 kWh of solar energy annually [17-18]. The ILC's annual energy use (steam and electricity) is 3,750,000 kWh, meaning that solar power alone could generate 20% of its current energy demand. With an optimally formatted building structure and efficient envelope design, this percentage would increase significantly, because building energy use would decrease substantially.

Figure 4. *The R.W. Kern Center at Hampshire College is a certified Living Building at Hampshire College [21].*

While exact potential energy savings are unknown, the success of many LBC-certified buildings indicates that the ILC, and other similar buildings, could realistically have been designed to reach 105% energy production through better structural design, envelope improvements, and renewable energy production. For example, the R.W. Kern Center, seen in Figure 4, an academic building at Hampshire College, has a

61% lower EUI than the ILC [19]. If the ILC had been originally constructed with the LBC specifications in mind, this building would have succeeded in reaching 105% energy production. With this analysis, we maintain that UMass will benefit from transitioning to LBC as a green building guideline for all future construction.

W.E.B. Du Bois Library

The campus library serves as a building model with a low roof surface area to total building area ratio. In this instance, solar potential is lessened, making energy use reduction a vital approach. This is important in both retrofitting current buildings of similar dimensions and constructing new buildings.

Due to lack of roof space, tall and slender buildings are unable to rely heavily on solar energy as a production method. The roof solar potential of the library is currently 266,000 kWh per year, only a third of the ILC's [17-18, 20, 22]. Therefore, satisfying the LBC guideline of generating 105% of its building energy presents a challenge. In these instances, reducing the building's EUI is crucial to achieving net-zero energy. To accomplish this, the building envelope should be reinforced to reduce the heating demand, and locations of potential heat exchange such as windows, roof, and doors should be carefully resealed. Additionally, the transition to energy efficient light bulbs and appliances can significantly reduce energy demand.

The Pertamina Energy Tower in Indonesia, the first net-zero skyscraper, utilizes a solar panel covered walkway surrounding the facility to generate sufficient energy to power the building [23]. The Pertamina Energy Tower can be used as a model for future campus buildings of similar layouts in implementing LBC principles from the initial design process. Another example of a tall sustainable building is the Zipper Building in New York. Instead of being built with net-zero energy in mind, a design team proposed various energy-reducing tactics. These included implementation of PV panels as rain shields, increased insulation, and optimized glazing placement to maximize natural light and heat [24]. The building's energy use was analyzed and revealed to have decreased by 77%, suggesting that similar results can be expected from other tall and thin buildings.

Though large buildings such as skyscrapers are more difficult to renovate for energy generation, better insulation techniques and implementation of green technologies prove significant reductions. Renovating existing UMass buildings to LBC standards will require substantial retrofits to power buildings renewably. On the other hand, any style of building that implements LBC guidelines from the beginning stages of design will more easily be able to provide 105% of the building's energy demand. Renovating existing UMass buildings with LBC's philosophy in mind will help reduce existing emissions, while transitioning to this building standard moving forward will eliminate all future building emissions and reduce overall campus energy use.

6. Project Pros and Cons: Costs, Advantages, Disadvantages and Challenges

When considering the implementation of any energy proposed energy reduction strategy, it is crucial to weigh both the advantages and disadvantages. In addition to considering the potential energy use and carbon emissions reductions, there is a need to take a holistic view of sustainability through examining the "Four Es": Energy, Economics, Environment, and Equity [25]. When it comes to LBC buildings the pros substantially outweigh the cons, supporting future implementation of the Living Building Challenge at UMass.

Energy Magnitude

Although it is difficult to determine exact energy reductions that can be predicted in new and renovated buildings following LBC guidelines, data from existing LBC buildings can be used to predict approximate energy savings. The Bullitt Center in Seattle, seen in Figure 5, generated an EUI of 41% lower than that of a similarly sized LEED-certified building [27]. Similarly, the Kendeda Building in Georgia exhibited an estimated EUI of 71% lower than a building of similar occupancy [28]. Since Living Buildings produce over 100% of their own energy demand, they help to compensate for other buildings and reduce overall campus energy use.

Figure 5. *The Bullitt Center in an example of a successful Living Building in Seattle, WA. Its size of 52,000 Sq. Ft. is comparable to many buildings on the UMass campus [26].*

Implementation of LBC will require a change in perceptions regarding LEED's energy efficiency and construction costs. Contrary to popular belief, building to LEED standards does not ensure energy efficiency. This assumption will be difficult to change on a large scale, but is necessary in order to begin a campus-wide transition towards Living Building principles. Additionally, a transition to LBC building guidelines for future buildings will not significantly reduce the energy needs of the existing buildings on campus. It may be difficult to reach net-zero carbon emissions by 2030 without LBC renovations and other emission reduction and offset methods.

Economic Consideration

Zero Energy Certified buildings, a subset of LBC, have exhibited lower average construction costs than the 20 most recent UMass projects, when considering both renovations and new construction [29]. The average Zero Energy Certified building costs $512/sq.ft. to build, while the average recent UMass building costs $679/sq.ft. [29]. Both values cover a broad range of building sizes and uses, the UMass average is much higher when compared to Zero Energy Certified. The paradigm shift for the Living Building Challenge when compared to traditional green building standards is the truly integrated design process. Each aspect of a building is considered together, and adjustments to a building's design at every stage must immediately be reflected in energy modeling. This strategy is quite intuitive, yet traditional design teams today operate somewhat autonomously until very late in the design process. Only through this integrated process can a team effectively work towards a net-zero goal. Given that teams are truly working synergistically (i.e. renewable energy is not added as an afterthought), construction cost calculations are presumed to include energy installations as well. Lower construction cost is a huge advantage that LBC-focused buildings hold over typical UMass buildings and over many other proposed campus energy reduction strategies.

Net-zero energy buildings exhibit lower costs of operation, given that they annually generate more energy than they consume. The annual cost to power and maintain the building is low, as it provides energy for itself. Additionally, the required continuous auditing of energy performance ensures that initial construction design elements create long-term reductions in energy use. Frequent performance monitoring allows for proactive maintenance to maintain optimal energy performance. Consistent monitoring ensures long-term savings and energy use reductions, despite minimal short-term material and labor costs.

Although there are many economic benefits to the Living Building Challenge, it is undoubtedly a departure from traditional green building design. Not all contractors, consultants, and engineers have had experience with LBC. Additionally, considering that LBC is more of a philosophy than a building standard, no amount of money can guarantee Living Building certification. Each building has different specifications that require unique solutions to reach LBC certification.

Environmental

Successful implementation of the Living Building Challenge will result in buildings that produce 105% of the annual energy they consume, meaning that all energy-related annual carbon emissions would be eliminated. Furthermore, local sourcing of materials and net-zero water use, other Imperatives of the Living Building Challenge, create buildings with minimal environmental impacts.

Eliminating carbon emissions has some indirect environmental costs. Estimates for the carbon emissions of a solar panel over its lifetime fall between 0.07 and 0.18 lbs of CO2 equivalent (CO2e) per kWh compared to 0.6-2 lbs of CO2e/kWh for natural gas, and 1.4-3.6 lbs of CO2e/kWh for coal [30]. Though solar panels emit less carbon over their lifetime, some currently-installed panels are composed of toxic compounds, such as gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride, all of which are potential health and environmental hazards [31,32]. Additionally, there are concerns for the global capacity to recycle these panels [30]. Given the recent rise in adoption of solar panels, the future effects of their mass disposal are unknown.

However, a growing market for recycled minerals from solar panels is creating opportunities for panel producers to reduce their dependence on mined materials [33].

Equity

The Materials and Equity Petals of LBC account for social equity with regard to the local community. The Materials Petal mandates that 50% of the construction budget is spent in a 1000 km radius to support regional businesses. The Equity Petal dictates that a large percentage of workers must be hired locally. Minority and female employees must have fair representation to encourage diversity in ideas and experiences, which are necessary in addressing the unique challenges of designing a Living Building [10]. Given these Imperatives, the Living Building Challenge offers a framework for buildings that are equitable to all in the community, at every step of the development process.

Many Living Buildings utilize solar to generate energy. The mass demand for solar panels and the existence of several different types of panels make it difficult to trace back to the mines to judge the working conditions. Some minerals in solar panels, including gallium, are derived from the refinement of zinc and aluminum ores [34]. The global distribution of these resources makes it difficult to trace labor equity at every level of production [29].

The benefits of implementing the Living Building Challenge at UMass outweigh the drawbacks; therefore, UMass should adopt LBC guidelines for all future buildings.

7. Conclusion

The University of Massachusetts recognizes its role as a model for sustainable campus practices. UMass has ambitiously taken on the challenge of achieving carbon neutrality by the year 2030. Currently, 85% of UMass' energy is utilized to heat, cool, and support campus buildings [3]. To reduce emissions associated with buildings, UMass' Green Building Guidelines rely on LEED. Pursuing LEED was intended to illustrate the University's commitment to developing sustainable infrastructure. However, LEED certification is not earned through actual building energy use outcomes, but instead by reaching a point minimum on a checklist. The campus is not on track for carbon neutrality by 2030 since implementing LEED, demonstrating that LEED is insufficient as a framework for this goal.

By prioritizing actual energy outcomes, transitioning to the Living Building Challenge will create real reductions in building-related energy use and emissions. Implementing the Living Building Challenge requires planning from early stages of the building design process. Building shape, orientation, and basic design are major factors in determining the success of a potential Living Building. Efficient technologies are implemented to reduce the energy demand of the building, and renewable energy sources account for the remaining energy need. Once completed, a Living Building will produce 105% of the energy it uses [10]. The Living Building Challenge enables buildings to balance cost and energy performance in a way that results in lower costs of construction when compared to traditional buildings of similar size and function [34]. Shifting to the Living Building Challenge for future campus buildings will eliminate increases in overall campus emissions, even as the University expands. When applied to renovations, the LBC philosophy will further decrease existing campus emissions.

Our team recommends going beyond the current Green Building Guidelines to the Living Building Challenge. All future campus buildings should strive for LBC certification, in addition to the state-mandated LEED Silver certification. In cases where LBC cannot be met, either in new construction or renovations, the criteria should be followed as faithfully as possible to produce a building with the lowest possible energy impact. This proposed solution will reduce future construction costs, eliminate carbon emissions from future buildings, reduce the emissions from existing buildings, and distinguish UMass as a pioneer in the movement for institutional sustainability.

8. Appendices

A. Data for Figure 3
  a. Projection 1: new construction follows LEED
    i. UMass average EUI, in kBTU/sq.ft/year = 100.44
    ii. 25,000 sq.ft. * 100.44 kBTU/sq.ft./year
    = 2.5 million kBTU annual increase in annual energy load
  b. Projection 2: new construction follows LBC
    i. R.W. Kern EUI = 23.4 kBTU/sq.ft/year
    (new LBC construction EUI assumption)
    ii. 25,000 sq.ft. * 23.4 kBTU/sq.ft./year * (-0.05)
    = 29,250 kBTU annual reduction in annual energy load
      1. Based on LBC requirements for new construction, Living Buildings generate 105% of their energy needs
  c. Projection 3: new construction follows LBC, renovations follow LBC
    i. Projected renovated UMass EUI = 50% * 100.44 = 50.22 kBTU/sq.ft./year
      1. Based on LBC requirement of a 50% energy use reduction for renovations
    ii. LBC reduction in energy load for new construction – renovation's previous energy use – 5%*renovation's LBC energy use
    = –29,250 kBTU – 50,000 sq.ft.*100.44 kBTU/sq.ft. – 5%*50,000 sq.ft.*50.22 kBTU/sq.ft./year
    = 5.18 million kBTU annual reduction in annual energy load

B. Yearly Energy output of Solar Panels on Bullitt Center calculations:
(expected 230,000 kilowatt hours per year)/(13,400 square feet of solar collection) = Estimated 17.1 kWh/sq ft

C. W.E.B Library solar panel calculations:
420,000 sq ft / 27 floors = 15,555 sq ft per floor
Solar Production: 15,555 sq ft of roof * 17.1 kWh per sq ft PV solar = 266,000 kWh roof production

D. Zipper building EUI calculations:
Energy use: (56,360,000 kBTU) / (1,000,000 sqft) = 56.36 kBTU/sqft

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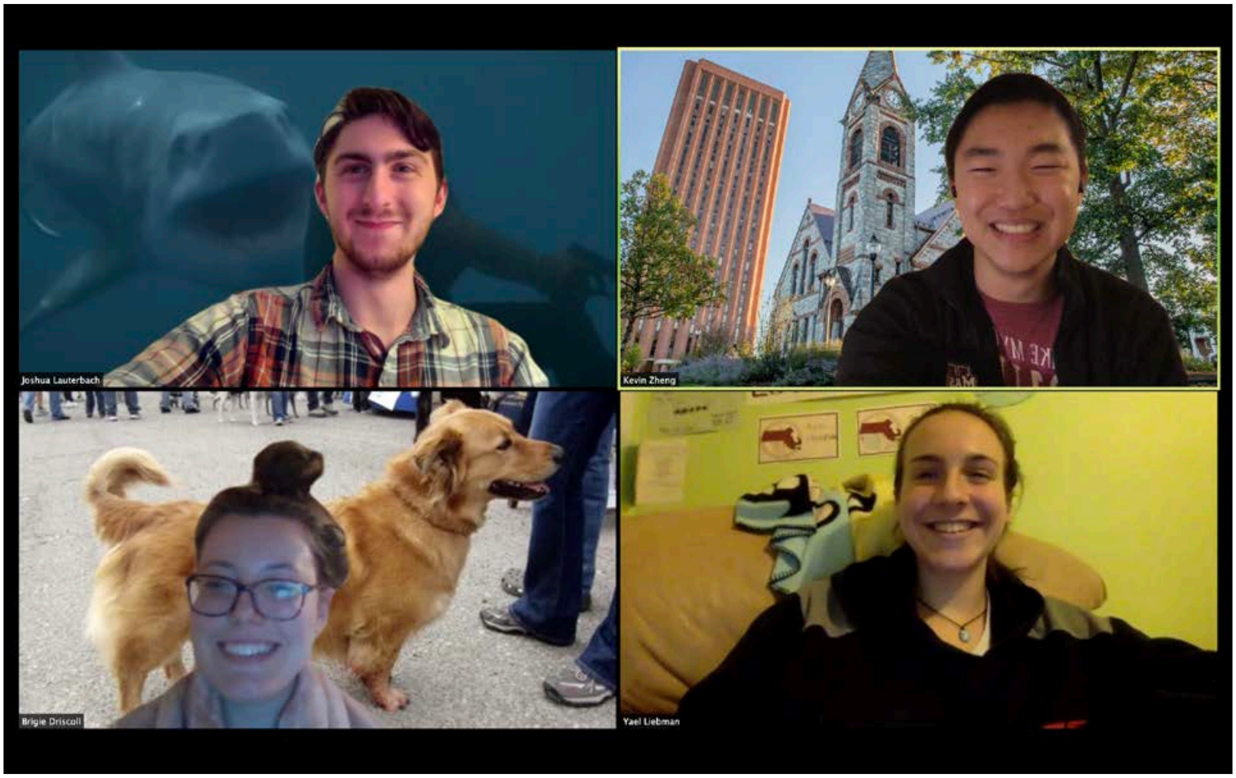
Lastly, we would like to thank the Carbon Mitigation Task Force team for giving our work your time and attention. Your work is incredibly important to the UMass community and to the future of the planet, and we thank you for your contributions to sustainability.

With love,
The Living Building Challenge Team



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