Smart Buildings, Green Campus: Reducing Campus Emissions with Smart Technology

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1. Executive Summary

Nine years remain to reach the goal of campus-wide carbon neutrality. In order to make substantial progress in maintaining that deadline, immediately addressing the emissions of buildings which account for the majority of UMass Amherst's carbon footprint, is imperative to ensure the timeline remains possible. One means of achieving this goal is retrofitting buildings with smart technologies. At UMass, heat over-expenditure results in a large portion of carbon emissions and energy waste. Fortunately, the technology and resources are now available and accessible to reinvent exactly that cycle by retrofitting existing buildings with green adaptations.

Green building alternatives are available to apply to existing buildings, rather than having to demolish and rebuild these campus facilities, effectively overspending time and money. By installing smart technologies such as self-automated HVAC-heating systems, not only will it prevent the current programming of systematic overheating, but it will ensure that heat energy wasted will be rerouted into outlets where it can be utilized.

Remaining stagnant with the current rate of building retrofit will result in the guaranteed negligence of the 2030 neutrality deadline and in increasing levels of preventable heat entropy polluting the campus environment. Implementing smart technologies in the buildings that span the nearly-1500 acres of campus will immediately mitigate a large portion of emissions and keep on track to not only meet the 2030 deadline, but the less-forgiving deadline of irreversible climate change that our planet faces.

2. Introduction

The threat of climate change has become extremely urgent due to collective negligence in the past decades. For decades we have known of the disastrous consequences of climate change on the health of the environment and humans. Humanity continues to avoid action regarding climate change because it is not bad enough yet. The actions of a few are putting the entirety of humanity and many other organisms in a precarious position. Immediate avocation and innovation is necessary to avoid irreversible tipping points. Chancellor Subbaswamy has challenged UMass to rise to the occasion and be truly revolutionary by reaching carbon net neutrality by 2030. UMass Amherst is the largest emitter in Massachusetts, accounting for 14% of emissions statewide [1]. Drastically reducing carbon emissions at UMass does not just benefit the campus community but would benefit the entirety of Massachusetts. 85.3% of UMass's emissions are building related [2], and so our group has researched Smart Technology: A versatile retrofit that will be able to make a huge step towards a greener campus.

Smart Technologies are already in use on campus and can be applied to new buildings and as retrofits. A smart building has sensors to detect conditions, a central processing unit, and control to adjust conditions based on baselines and user preferences. The central processing unit is key to reducing emissions as it will automatically adjust building conditions, including but not limited to ventilation, temperature, and humidity, based on indoor and outdoor conditions and occupancy levels. Right now, UMass runs on a "better more than less" mantra, overheating buildings at times to avoid dangerously cold temperatures. By keeping buildings at optimal conditions consistently, there will be no oversupply of energy, and therefore reduce energy wastage.

3. Problem Statement

The University of Massachusetts Amherst is the largest emitter of carbon dioxide statewide, accounting for fourteen percent of state emissions [1]. In order to rectify its emissions, the University of Massachusetts Amherst has committed to net zero emissions by 2030. One way to achieve this goal is by addressing the energy efficiency of the buildings on campus. Currently, the University of Massachusetts has 280 buildings that contribute to 85.3% of campus carbon emissions for a total of 124,900 Megatons of CO_2 per year, as shown in Figure 1 [2]. By decreasing the energy usage intensity (EUI), of buildings on campus through renovations, the University of Massachusetts Amherst can decrease carbon emissions.

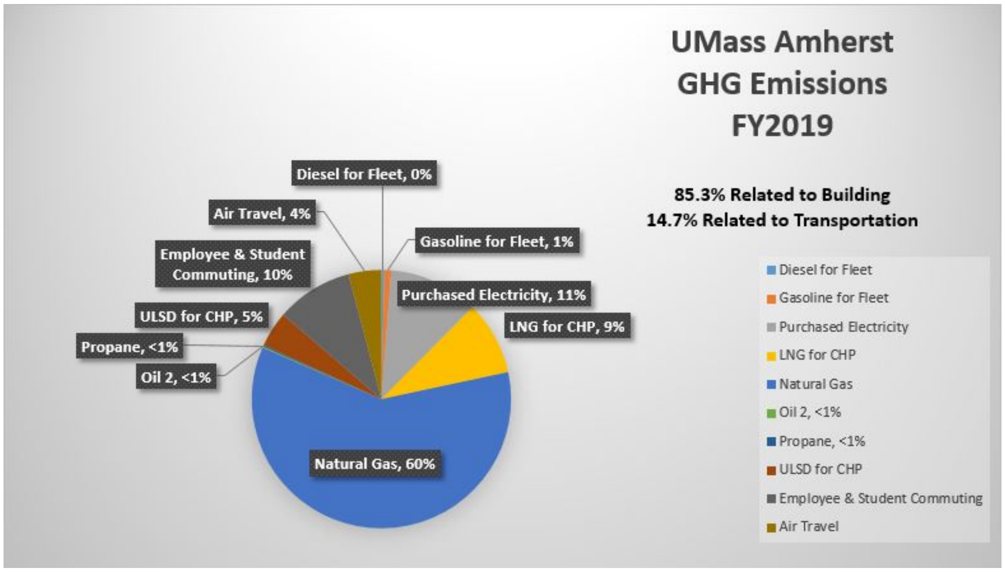

Figure 1: Depicted is a breakdown of GHG emission sources in UMass Amherst, where building emissions can be attributed to natural gas, other CHP-related fuel usages, and grid electricity [2].

Energy usage intensity is the amount of energy used per square foot per year of building. EUI is affected by the design of a building, its energy system, and operation management [3]. The climate region also plays a significant role in EUI but will pose less of a challenge for planning renovations at UMass since it is a constant factor for all buildings. Many passive methods of regulating thermal exchange will not be accessible for renovations, since they largely deal with orientation and window placement, which must be considered in the design of a building. Instead optimizing the performance rather than the design of existing structures is a more probable solution.

One of the challenges with decreasing the EUI of buildings at the University of Massachusetts Amherst is the varied ages of buildings on campus. UMass has 12.8 million gross square footage of structures on its campus [4], 10 M GSF was developed between 1960 - 1980 [2]. Consequently, the energy efficiency of these buildings is limited to the technologies of their times. This is reflected in the EUI of buildings on campus. Goddell and Morrill 2 have the some highest EUIs of buildings powered by steam based on the FY2018 report and were built in 1934 and 1960 respectively [5].

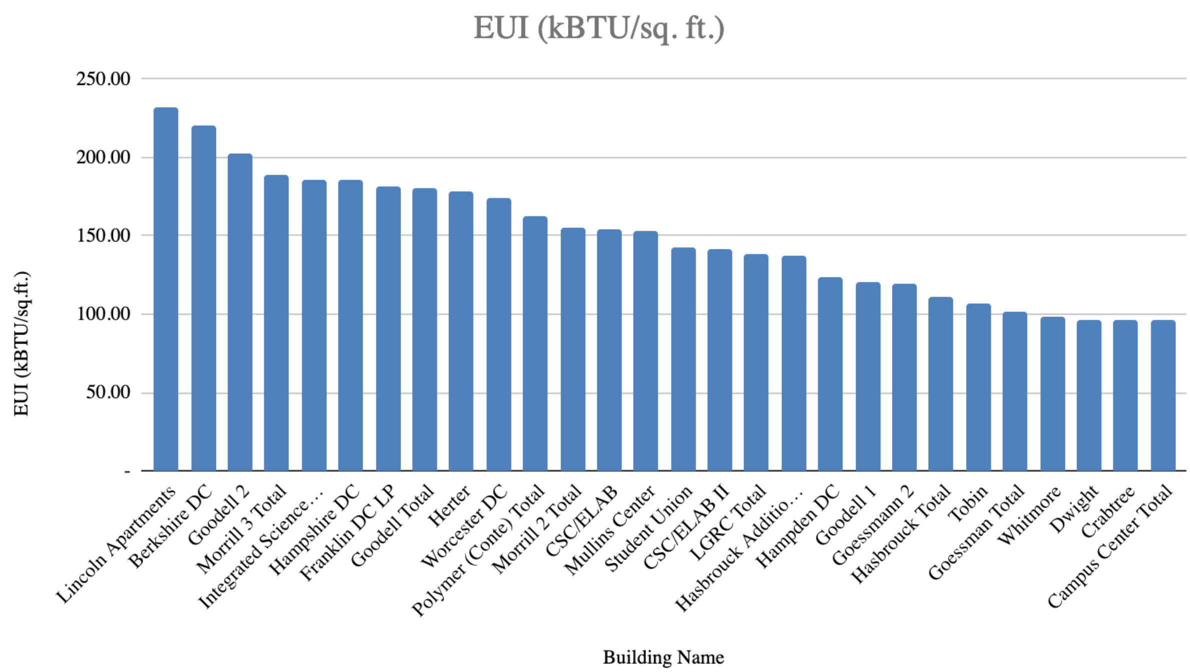

Figure 2: A graph of buildings with the highest EUI at UMA

Building size also impacts the types of renovations that can take place. The University of Massachusetts Amherst houses over two hundred buildings from the tallest academic research library to dorms and laboratories. The shape and size of a building greatly contribute to its EUI. A compact building is most desirable in terms of reducing thermal heat loss, but must be balanced with passive solar lighting potential [6]. However, Building shape and size cannot be altered through energy retrofits and thus must be accommodated by other EUI reducing systems.

Lastly, one of the greatest impacts of a building's energy usage intensity is the purpose and type of that building. UMass Amherst houses a great variety of building types including research laboratories, dining halls, and dormitories. Based on the FY18 Water and

Steam Total Report, building type is a greater contributor to the EUI of a building than its age [6]. Based on Figure 2 it is evident that laboratory buildings and dining commons have the hightest EUI. This is supported by the Carbon Mitigation Plan that states laboratory spaces use four to five times more energy per square foot than a typical classroom [4]. Many laboratories are in operation 24/7 and have specific temperature and humidity requirements. This will impact renovations on lighting and ventilation systems to focus on higher efficiency.

Conversely, dormitories and classrooms waste energy by not regulating lighting and heating systems when the building is not in use. Even in dormitories where temperature sensing is in place, such as the Commonwealth Honors College, there are inefficiencies. These buildings rely on imprecise outdoor sensors to adjust indoor conditions to resident comfort and unsurprisingly, the residents are often uncomfortable. Based on a survey conducted by a group in iCons 3 studying overheating of dorms, it was found that students in most residential areas on the UMass Amherst campus believed their rooms were warmer than what was comfortable. In order to ensure comfort for residents inside the campus buildings, it would seem obvious that indoor temperatures should be the sole metric taken into account when deciding how much heat to be pumped into a building to reach a comfortable temperature. However, the reasoning for utilizing outdoor temperatures can be explained as follows:

1. It is safer for residents to be too hot than too cold.
2. By the time the indoor temperature is too cold and indicated that the building requires it to pump in more heat, it is already too late.
3. Based on outdoor temperature, the building preemptively pumps heat into the building to ensure the indoor temperature is above a certain cold temperature threshold consistently leading to overheating.

The overarching algorithm of this feedback system can be extrapolated to many aspects of campus building management from heating to ventilation. This idea of “better too much, than too little” is especially harmful to our environment and our goal of reducing carbon emissions. Increasing building efficiency through smart retrofits not only will reduce the EUI of buildings but also reduce the total carbon emissions on campus.

4. Tech and Implementation Explainer

Currently, UMA is the largest carbon dioxide emitter of all state agencies. [7] Campus buildings contribute up 85.3% of the total campus emission. [8] In order for the state to meet the state-wide decarbonization goal of net-zero greenhouse gas emission by 2050, UMA must target the biggest energy consumer: buildings. Implementing smart technologies in suitable buildings on the UMA campus can significantly reduce the EUI of buildings, reducing carbon emissions and creating energy savings [9].

Smart technology can be defined as a sensor/control network that can be remotely controlled, and interacted with by users, therefore making buildings smarter covers a wide breadth of technologies. This study focuses on implementing several basic components that control and regulate heating and lighting systems to optimize performance based on software currently in place at UMass Amherst. First, accurate and reliable sensors must be installed to observe environment conditions and convert that information into digital data which can be remotely delivered to the second component. Next the control system is installed so the physical building parameters (heating, lighting, ventilation, etc.) can be adjusted based on remote instructions. A central software platform receives information from sensors, compiles the data, and turns it into instructions that can be communicated to the control systems. Actual implementation of sensors and control systems will differ depending on building types.

The central software platform is what glues the entire smart network together, and so this should be addressed first. There are two types of building automation that exist: Automated System Optimization (ASO) and Building Automation Systems. ASO uses information communication technologies (ICT), like computer networks, satellite systems, cell phones, etc., to relay information and store real time data that helps predict energy demand and connect building systems together. BAS on the other hand, relies on predetermined setpoints for building operation and reacts to real-time conditions instead of predicting them. UMass Amherst already has a central software platform called Metasys, a BAS system made by Johnson Controls, and so our group will be focusing on BAS instead of changing the existing infrastructure to ASO. Metasys is a massively underutilized tool since it relies on imprecise sensors to crudely adjust control systems (lighting and heating), so that new sensors could be integrated into in order to adjust control systems in order to maximize energy efficiency. This study outlines how to expand Metasys by integrating more precise and versatile components to work with. In addition, Metasys, acts as a central remote control terminal, which with smarter technology, would allow maintenance services to accurately adjust campus conditions from anywhere.

One of the most energy-intensive building types on our campus are laboratories. Laboratory spaces use four to five times more energy per square foot than a typical classroom due to unregulated ventilation [10]. Many university laboratories use more than ten air-changes per hour (ACH), resulting in heavy energy consumption [11]. Implementing air quality sensors, occupancy sensors, and real-time ventilation controllers would save 40% of energy consumption for a 70,000 square foot laboratory building [9]. Air quality sensors measure for potentially harmful contaminants, like carbon dioxide, particulates, and volatile organic compounds. Occupancy sensors detect the presence of a person in a room. Because sensors “are programmed to detect ultrasonic pulses and infrared, heat-based movement” [13], the system is able to accurately access activity levels at any time. Data from both types of sensors adjust the ACH accordingly instead of relying on a default setting. As a result, the number of ACH decreased by one-third during normal operations and decreased by half when unoccupied. Real-time ventilation control is a smart lab feature that is both economically feasible and impactful, with a 6-8 years payback period.

By implementing these simple smart technologies and other energy-saving practices, university UC Irvine reduced the energy consumption of its laboratories by an average of 60% [11]. Additionally, UC Irvine developed a methodology for retrofitting any laboratory with these game-changing technologies to achieve similar results. Their only restriction is that labs that are Biohazard level 3 and 4 must follow strict guidelines and therefore are too dangerous to retrofit, however, this is a small minority of laboratory space on campus.

The Integrated Learning Center (ILC) exemplifies a successful smart building currently on the UMass campus. As one of the most highly trafficked buildings on campus, the building remains LEED Gold Certified, which indicates high energy and water efficiency, emission reduction, and improved indoor environmental quality [12]. By connecting their daylight and occupancy sensors to the Johnson Controls Metasys Building Automation System (BAS), the building is able to be monitored remotely. When occupancy is detected, the heating, ventilation, and air conditioning (HVAC) system and lighting are programmed to stay on. When a room becomes unoccupied, the light will shut off and the room temperature will return to the default setting. Daylight sensing is used to adjust the amount of artificial lighting used. If the sensor detects that there is enough natural light available, high-level artificial lighting shuts off and low-level lighting will be used instead. The Metasys BAS also monitors heating and ventilation in the building by automatically opening or closing windows when airflow or indoor temperature regulation is needed [13]. With these technologies in place as part of its green building design the ILC has an EUI of 42 kBTU/SF, which is one of the lowest of all buildings on campus [17].

Although similar strategies, like utilizing occupancy sensors, can be taken from both laboratory and classroom settings and employed in dorm settings, there are other smart technologies that should be addressed specific to dorm buildings. Because dorm buildings in the Northeast and Central area still rely on heat delivered by steam, "each room in the hall has a radiator with a thermostatic hand-value that controls the amount of steam that enters the radiator" [15]. There are concerns that during the transitional period of heating and non-heating seasons, optimal heating conditions are not met. To address such concerns, smart radiators called Radiator Lab Cozy should replace the current radiators in the respective dorm buildings. While being mindful of space constraints in buildings, users would be able to control heating temperatures and save up to 45% on heating costs and 45% reduction in fuel use. As a retrofit-friendly technology, this easily integrates with all types of radiator [16].

Smart lighting retrofits are a universal retrofit that can be applied to any building type. By installing occupancy sensors and web-based lighting control management systems, energy consumption is estimated to be reduced by 11% [9]. Just implementing LED lighting greatly reduces electricity loads by decreasing the wattage, achieving "30% in energy savings" while "implementing advanced lighting controls offers an additional 44 energy savings with a payback of less than five years" [9]. UMA already has the experience and technology in implementing smart lighting technology in buildings like the ILC. In addition, lighting retrofits are not limited to existing wiring locations and so controls and lighting designs are very retrofit-friendly. This proves that implementing smart lighting is not only financially viable and environmentally beneficial, but also technically feasible.

While smart technologies can greatly reduce building emissions, retrofits may not always be cost effective. As a result our group has identified which buildings would be best suited for smart technologies retrofits. While dining halls and older buildings have the highest EUI as seen in Figure 1, they are not the target of our study. Dining halls individually have a high EUI in comparison to other buildings but proportionally account for less of total campus emissions, as shown in Figure 1.

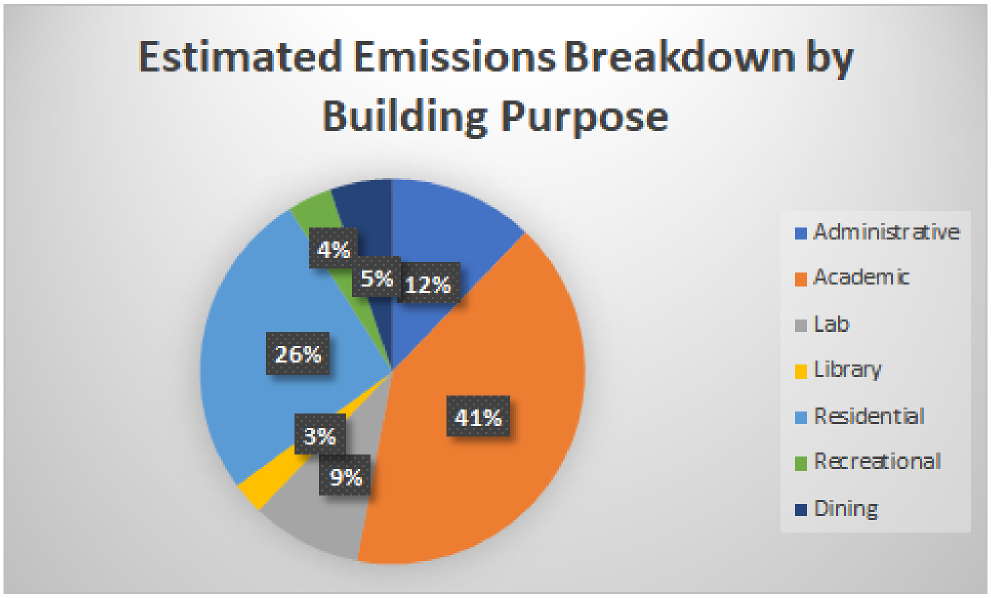

Figure 1. Above is the distribution of building emissions categorized by building purpose.

Additionally, research on smart technologies in large scale dining buildings does not exist, making it implausible to retrofit these buildings. While older buildings do account for a significant portion of campus emissions many of their operating systems do not have the digital components necessary to adapt to smart technologies. Smart technology retrofits would require completely replacing these systems which is unlikely to be cost effective. However, if these systems are scheduled for maintenance or replacement investing in smart technologies during these retrofits would be a good investment. To make the greatest impact our group recommends targeting labs built after 1990, like the ISB, Conte Polymer lab, LSL, and the Comp Sci Engin Lab. These buildings likely have the digital components necessary to implement smart technologies and would have a significant impact on reducing emissions. Other buildings well suited for smart technology retrofits are those with a predictable workflow and occupancy levels because standards can easily be established to reduce energy waste. This would include academic buildings without labs, light dry labs, student labs, and office spaces.

In conclusion, smart technology proves to be a powerful investment for energy efficiency. By retrofitting the ventilation, lighting, and heating system in our UMass buildings according to their building types and sizes, our campus will expect drastic carbon emission reductions and increased cost savings over the years.

5. Pros and Cons

In considering the feasibility of introducing better smart technology into the UMass Amherst campus, it is important to maintain a realistic and unbiased perspective towards its usefulness.

<u>Energy Magnitude</u>

Through our study, our group has determined that energy saving totals for the entire campus can be attributed to three factors: size, age, and purpose. The size will determine how much we scale the EUI by, to determine the building's total emissions. Age will determine the size of the technology gap, where higher age will lead to larger energy savings from bridging that gap (but also increased costs which will be addressed). Finally, the purpose of the building will tell us what types of retrofits can be enacted, which will also affect our total potential energy savings.

Utilizing estimates from a smart building study conducted by the American Council for an Energy-Efficient Economy, and campus data, we are able to generate the following savings for UMass Amherst [26]:

Note: We would rather produce an underestimate than an overestimate, and so buildings that are classrooms with lab space will be classified as 25% lab space, despite the actual number being higher.

Table 1: Breakdown of Potential Emission Savings due to Smart Technology Retrofits at UMass Amherst

Building Type:	% of Average Expected Energy Savings per Building	% of Total Building Emissions	% Saved of Total Building Emissions	% Saved out of Total Campus Emissions
Academic	11%	40.8%	4.5%	3.8%
Laboratory	40%	9.3%	3.7%	3.2%
Residential	6%	26.9%	1.6%	1.4%
Offices	23%	12.1%	2.8%	2.4%

For now, the most important metric we should look at here is the % Saved of Total Emissions, or the 4th column in Table 1 as it determines how much we can cut emissions with each building type. By implementing smart technology in Academic, Laboratory, and Residential buildings, we would be able to reduce the campus's total building emissions by 9.8%, and with Offices (which we did not originally consider) this would add an additional 2.8% in savings. This total potential 12.6% building emission savings is a great leap towards the Carbon Mitigation's plan of 20% reduction in building emissions by 2032, but of course we must take the cost of these smart retrofits into account as well.

<u>Economics</u>

Just like any renovation project, there are upfront costs. With the limited resources and mounting debt, it would become difficult to convince UMass Amherst to finance such retrofits. The cost installation varies but older buildings are more likely to cost more. Excluding installation costs, the wireless sensors could cost from $150-$300 each with a life expectancy of 15-30 years [18]. Wired sensors could cost from $50-$100 and $1.60 per linear foot of wiring [19]. The lighting management system recommended for classrooms would cost $1.15 per square foot. Advanced lighting controls as seen in the Integrated Learning Center (ILC) would cost about $2-4 per square foot [20]. The most expensive smart technology is building automation. Traditional Building Automation System (BAS), as found in ILC, would cost $1.50-7 per square foot. Despite the costs, it would save 10-25% of energy. [4] However, this saving is relevant only in larger buildings with over 100,000 square feet. Thus, depending on the building size and type, certain smart technology may not be as effective.

Building	***Type***	***Sq ft***		**BAS total cost estimation**	**Wireless sensors cost estimation**	**Advanced lighting controls**
Morrill I and IV	***Academic, lab***	**183,701**		$270,000 - $1,300,000	$90,000 - 180,000	$400,000 - $700,000

*sensor cost estimated by assuming 3 sensors per room, which each room averaging 900 square feet [27].

Installation is an additional cost that must be taken into account as well, however this is outside the scope of our project. We believe that installation costs will rise exponentially with the age of a building and so it might be more effective to focus on retrofitting buildings built in 1980 and newer with smart technology.

Despite these drawbacks, implementing heating and lighting sensors to make campus buildings smarter has a significant impact on reducing building emissions, which is the ultimate goal of the Carbon mitigation plan. The integration of smart technology with UMA campus buildings will potentially reduce the emissions that they produce by up to 40% [22]. This reduction is achieved as a result of added occupancy and air quality sensors, and remote lighting and heating controls. The Carbon Mitigation plan states building emissions must be reduced by 20% for large retrofit projects, implementing smart technologies achieves emission reductions double this goal [23]. The surplus in emission reduction from smart technology would account for unrelated sectors of campus where emissions cannot be easily reduced.

<u>Equity</u>

Baselines for occupant comfort are outdated and do not reflect the physiology of a diverse population. ASHRAE 55 and other temperature baseline standards were established in 1960 from an empirical calculation based on the metabolic rate of one 40 year-old Caucasian male [28]. Consequently these standards do not reflect the ideal air quality conditions for the diverse population at UMA. Dr. Boris Kingma and Dr. Wouter van Marken Lichtenbelt proposed a biophysical model based on a diverse sample population to establish new baselines for building temperature standards in their 2015 study "Energy consumption in buildings and female thermal demand" published in *Nature Climate Change*. Using a biophysical model as a baseline condition for smart technologies that regulate temperature and humidity would create an environment that is more comfortable for all occupants, reducing the likelihood of temperature controls being changed manually. Adjusting automated systems and other behaviors to manually change air conditions negates the energy savings and emission reduction benefits of automated systems [28].

Modernizing buildings will provide equal access to comfortable building spaces for students and faculty at UMA. Based on a 2008 literature review written by Dr. Barry P. Haynes self reporting surveys show statistically significant correlations between productivity and comfort levels in work environments [29]. Implementing smart technologies will automate ventilation, temperature, humidity, and lighting to optimal comfort levels based on the occupants inside that space. By optimizing lighting and air quality conditions in buildings, UMass will be providing an environment open to all students and faculty who may not otherwise have access to healthy and productive spaces.

Additionally, by maintaining optimal conditions for more of the time as a result of improved sensors and control systems, we are also able to improve the comfort of our campus residents and their productivity [24]. The automated system's main goal is to maintain the highest level of comfort for its inhabitants by reducing emissions as a side benefit. Real-time and accurate sensing will allow the building to precisely change its conditions to achieve an effective "homeostasis" as previously mentioned. Internal conditions would stay within the comfortable range for the entire time, and there would never be underheating or overheating due to the responsiveness of the building automation. These conditions can also be individualized as well, as thermostats that must be installed for temperature sensing in each room, can also allow for personal changes according to individual perception.

While there are many advantages to implementing smart heating systems to UMass campus buildings, digital security presents a challenge that cannot be overlooked in the planning and implementation process. Retrofitting up to century-year-old buildings with modern 21st-century technology, subjects these buildings to habitual building regulations. With any coding-based software to serve as the command center for a building, digital security is always prone to hackers and cyber attacks, so proper internet security measures must be put in place. If the computer behind a building's "homeostasis" were to become compromised, not only would it defeat the purpose and cause an uncomfortable temperature in the building, it could lead to everlasting damage within the software that could go far beyond just classroom comfort levels. It is important to consider the worth of software integration such as this from a financial standpoint, as evaluating the cost of the hardware and security measures could outweigh the value lost by the initial overheating with the current methods.

Environment

As with any new development in technology, the upstream, midstream, and downstream must be taken into consideration to ensure that the drawbacks do not hinder the benefits that can be superficially seen.

Environmentally, we believe that there may be a negative impact in the way that our sensors are sourced. UMass Amherst will have to carefully consider a technology vendor that can provide sensors, controls, and wiring without producing an excess of emissions or damaging the area. Technology is naturally made up of metals, minerals, and plastics, so due to the mining and manufacturing process, it may be impossible to completely avoid the environmental effects.

Additionally, the sensors and controls will require electricity to run, producing their own emissions. However the function that they provide in reducing emissions from buildings in other aspects will easily be better than the original emission rate of these buildings.

6. Conclusion

Through our group's study, we have found that implementing sensors in order to automate heating and lighting systems throughout UMass buildings will lead to a significant reduction of energy usage that will pay off the initial investment. One of the main challenges presented is the diversity of buildings on campus. Building and heating system types, as well as building size and shape, will impact the type and quantity of sensors needed and will each require unique automation systems. Additionally, older buildings may have energy inefficiencies such as drafty windows and doors that create energy waste that would not be resolved by smart technologies. Yet, in buildings identified most suitable for the implementation of smart technologies, there will be significant emission reductions that justify the cost of implementation. While smart technologies pose a cyber risk, UMass is equipped to create secure systems that will provide helpful energy usage data that can identify further inefficiencies, inspiring future retrofit projects.

While smart technologies are not the sole solution to achieving net zero emission at UMass Amherst they can be an effective first step. Since smart technologies are so versatile and vary from temperature and ventilation systems these retrofits can be applied to most buildings and project intensity can be based on need and budget. Building retrofits are already built in the carbon mitigation plan, if heating and ventilation systems are already going to be overhauled, replacing them with smart technologies is the smart decision. By targeting lab buildings that account for a significant portion of UMA EUI and office buildings that are well suited to smart technology retrofits this technology would be most effective at reducing buildings emissions.

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Appendix

Table 1 Calculations:

85% of UMass emissions are building related and 146,427.90 MTCO2e are emitted per year [8].

$Total\ Building\ Emissions:\ 0.85\ *\ 146,427.90\ =\ 124,464.72\ MTCO2e$

% Saved of Total Building Emissions = (% of Total Building Emissions)*(% of Expected Energy Savings per building)

% Saved out of Total Campus Emissions = % Saved of Total Building Emissions * % of Building Related Emissions (85.3%)