The Value of Green Building Technologies in Hotels: A Case Study on Denmark's Green Solution House

Photo Source: Green Solution House

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PREFACE

The research presented in this paper is motivated by my time studying abroad in Lund, Sweden through the University of Virginia's Global Sustainability Consulting Program. As part of the program, I visited Green Solution House to learn more about how businesses are incorporating the concept of "circular sustainability" into their operations, meaning that they are operating in a closed loop system with no significant waste outputs. I was fascinated by the design of Green Solution House and all of its innovative green technologies. Through this research, I hoped to gain a deeper understanding of how these technologies could be successfully implemented in other built environments. Additionally, the hospitality industry is of specific interest to me because of my experiences as a corporate responsibility intern at Hilton during the summer of 2019. My internship focused on how a global hospitality corporation is integrating concepts like "sustainability" and "corporate responsibility" into its business model. This research on Green Solution House also allows me to combine topics explored under both my Global Environments and Sustainability major and my Urban Planning minor to fully connect my studies at the University of Virginia.

ABSTRACT

The hospitality industry currently faces significant sustainability issues given the resource-intensive nature of the industry. Hotels require significant amounts of water, electricity, heating and cooling to operate and produce substantial amounts of waste. However, with the rise of green building technologies comes the opportunity for environmentally, socially, and economically positive changes in hotel building design and operations. Green Solutions House, a four-star hotel and conference center in Denmark, was designed to be at the forefront of green building innovation and is showing how the entire hospitality industry could use these technologies to not only be "greener," but to become more resource and cost efficient. This paper examines how three green building technologies are used successfully in Green Solution House—the pyrolysis plants, the integrated photovoltaic panels, and the biological water purification generators—to determine if such technologies would be beneficial for other hotels to implement. The research concludes that green building technologies can significantly decrease the environmental impact of the hospitality industry. However, the high upfront cost of these technologies is a common factor that limits their implementation. As hotels are typically operated as for-profit businesses, it is important to understand the long-term value of green building technologies. Thus, the viability of investing in green technologies must be analyzed through a financial lens. This paper concludes a Net Present Value (NPV) analysis on Green

Solution House's pyrolysis plant and integrated photovoltaic system to determine the financial value these technologies have for the hotel. Currently, not enough there is not enough publicly available on the specific components of Green Solution House's biological water purification system, thus a useful NPV analysis on this technology was not possible. The findings show that currently neither technology is creating a positive NPV for Green Solution House; however, with some situational changes like government incentives and public-private partnerships, these technologies could be profitable for Green Solution House. This paper also discusses how the successes of these technologies could change depending on the location of the hotel property.

INTRODUCTION

Green Solution House is a four-star hotel and conference center located on the Danish island of Bornholm. Before the building was transformed into Green Solution House, it existed as the Hotel Ryttergården. In 2015, Hotel Ryttergården underwent a $12.65 million USD renovation to become Green Solution House.[1] The new hotel currently totals a net floor area of 4,500 meters squared, contains 92 bedrooms, and occupies a land area of 65,000 meters-squared (approximately 16 acres).[2] Figure 1 shows the improvements in the capabilities and efficiencies of the newly renovated Green Solution House compared to the previous Hotel Ryttergården in the Active House Evaluation (see the Appendix for more information about the Active House Vision and Evaluation Model). Green Solution House was designed by the Innovation Team at 3XN, a Danish architecture firm known for its dedication to "ecological and behavior centric design research".[3] Green Solution House's design development was based on showcasing a holistic approach to sustainability and was inspired by the "Cradle to Cradle" life cycle framework, so all the materials used in the building are either fully recyclable or biodegradable.[4] The design of the building is certified to the standards of the German Sustainable Building Council and has achieved the Green Key label, which is an international eco-label awarded to hospitality facilities that fulfill strict criteria set forth by the Foundation for Environmental Education. Green Solution House also meets the criteria of the Active House

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1 *Green solution house*. (n.d.) Natural greenwalls. https://en.naturalgreenwalls.com/portfolio/green-solution-house/

2 Miller, S. (2015, July 7). Green solution house. *Construction 21.* https://www.construction21.org/case-studies/h/green-solution-house.html

3 *Our history.* (n.d.) 3XN. https://3xn.com/content/history/

4 Furuto, A. (2012). Green solution house / 3XN. *ArchDaily*. https://www.archdaily.com/199658/green-solution-house-3xn

Vision, which believes that buildings should be constructed to create healthier and more comfortable lives for the occupants without leading to negative environmental impacts.[5]

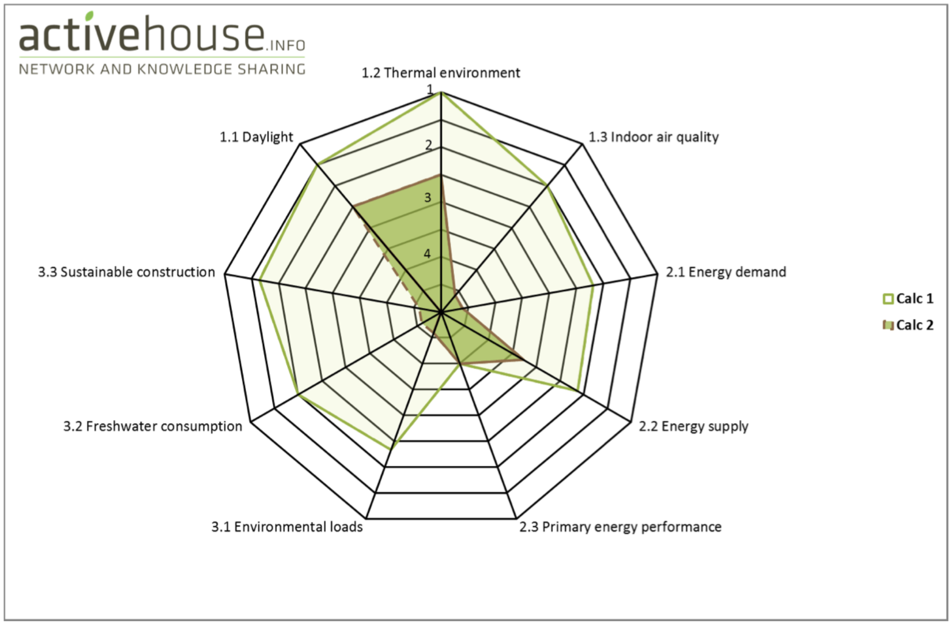

Figure 1: The Results of the Active House Evaluation Before (Calc 2) and After (Calc 1) the Renovation of the Building[6]

The mission of Green Solution House is to explore circular sustainability through innovative systems and strategies that contribute to the health of both the hotel occupants and the environment.[7] The hotel has three main goals: 1) to demonstrate green innovation and solutions to showcase a regenerative model that highlights biodiversity, healthy materials, renewable energy, clean water, and a circular economy, 2) to promote continuous improvement of technologies, materials, and methods to keep up to date with and test the most advanced technologies available, and 3) to enable knowledge sharing to foster the expansion of new knowledge within the field of sustainability on an international platform.[8] Green Solution House

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[5]Cradle to cradle. (2016, January 28). *Green solution house.* https://c2c-buildings.net/projects/green-solution-house/; Active house. (n.d.) *Our vision*. https://www.activehouse.info/about/about-active-house/
[6]Andersen, P. B., Worm, A. S. (2013). Active house evaluation: Green solution house. *Construction 21.* https://www.construction21.org/data/sources/users/15011/2015greensolutionhouseactivehouseevaluation.pdf
[7]*Exploring circular sustainability.* (2015). Green Solution House. https://gxn.3xn.com/project/green-solution-house
[8]Cradle to cradle, 2016.

currently features 75 interconnected green solutions within the hotel in focus areas including nature, water, light, air, energy, and materials. This paper will focus specifically on three of these solutions: the pyrolysis plant, the integrated photovoltaic panels, and the biological water purification system. As Green Solution House has successfully implemented so many green building technologies, it should be viewed as a viable example for other hotel buildings and operations.

The purpose of this paper is to highlight green building technologies used successfully in Green Solution House and analyze the costs and benefits of these technologies to explore the potential of such systems to become more widely adopted. With global warming becoming an increasingly prominent concern, the wider incorporation of green building technologies is an avenue to create significant, meaningful change that combats the threat of climate change. However, these green technologies face several barriers that could negatively impact their rates of implementation. One of the main barriers to the incorporation of green building technologies is the high upfront costs of many green technology systems.[9] This paper will show that the benefits from these systems, both monetary and environmental, outweigh the costs to encourage the greater adoption of these technologies in the hospitality industry.

Figure 2: Green Solution House Main Entrance[10]

[9]Ahn, Y. H., Pearce, A. R., Wang, Y. & Wang, G. (2013). Drivers and barriers of sustainable design and construction The perception of green building experience. *International Journal of Sustainable Building Technology and Urban Development*. https://doi.org/10.1080/2093761X.2012.759887
[10]Miller, 2015.

I. Waste, Energy, and Water Usage in the Global Hospitality Industry

The hospitality and tourism industry has become a strong catalyst for economic development as tourism is one of the world's four largest economic sectors. Currently, tourism is accountable for 15% of global "economically active" jobs and represents a global economic impact totaling $1.5 trillion USD.[11] Therefore, choices made by the companies in the hospitality industry will have significant and lasting environmental effects, especially in terms of important outputs such as energy usages, water consumption, food waste, and carbon emission rates.[12]

Waste is a major sustainability issue in all industries given its substantial impact not only on business profit margins and revenues, but also its negative impact on public health and the environment.[13] Although disposing of waste in landfills is one of the most commonly used waste management practices, landfills can lead to significant environmental degradation through their greenhouse gas emissions and contamination of both surface water and groundwater.[14] Land used for holding waste is land lost for other purposes. For every 40,000 tons of garbage that is produced, at least one acre of land is lost for future use. This equates to one acre lost every four days for the trash produced in New York alone.[15] The issue of waste is especially concerning in the hospitality industry which is known for being one of the largest global contributors of waste to landfills. Furthermore, a majority of this waste is composed of food and organic waste.[16] For example, the hotel industry in India produces approximately 644,486 tons of organic waste annually that gets sent to landfills. If the total amount of this waste was diverted from landfills through recycling, composting, or combustion, it would sequester the carbon equivalent of over 4 million trees for ten years.[17]

Additionally, the hospitality industry is expected to continue to grow. Without improvements to existing waste management operations, this will lead to significant effects on the industry's environmental footprint.[18] In 2011, hospitality operations in the United Kingdom

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[11] Dos Santos, R. A., Mexas, M. P., Meiriño, M, J. (2016). Sustainability and hotel business: Criteria for holistic, integrated and participatory development. *Journal of cleaner production.* https://doi.org/10.1016/j.jclepro.2016.04.098

[12] Dos Santos et al, 2016.

[13] Filimonau, V. Coteau, D. A. (2018). Food waste management in hospitality operations: A critical review. *Tourism Management*. https://doi.org/10.1016/j.tourman.2018.10.009

[14] Singh, N., Cranage, D., & Nath, A. (2013). Estimation of GHG emission from hotel industry. *Anatolia: An international journal of tourism and hospitality research*. https://doi.org/10.1080/13032917.2013.822817

[15] Singh et al, 2013.

[16] Filimonau et al, 2018.

[17] Singh et al, 2013.

[18] Priani, S. I., & Arafat, A. (2016, September 20). Reduction of food waste in the hospitality industry. *Journal of cleaner production*. https://doi.org/10.1016/j.jclepro.2015.07.146 ; Filimonau et al, 2018

produced 3 million tons of food waste at an estimated cost of $3.13 billion USD, which has since increased by $62 million to reach a cost of $3.75 billion USD as of 2016.[19] In the hospitality sector, the cost of food waste includes various factors like the disposal and transportation of the waste to waste management facilities and the labor cost associated with the disposal of the waste.[20] Instead of viewing this food waste as a short-term cost to diminish, businesses should change how their waste is managed. This will allow a currently wasted output to become a revenue generating input for hotels.[21]

Operations within the hospitality sector require consistent and reliable energy availability, which comes at a price. Every year, the hospitality sector spends more than $7 billion USD on energy usage.[22] On average, hotels in the United States spend $2,196 per available room each year on energy, which represents an average of 6 percent of the hotels' total operating costs.[23] However, if every hotel in the United States was able to reduce its energy costs through increased efficiencies or investment in renewable technologies, it is estimated that the industry could save over $730 million annually.[24] According to the Better Building Initiative at the US Department of Energy, exploring emerging renewable energy technologies and investing in energy efficient projects are two key ways the hospitality industry can create substantial and meaningful change.[25] This price of energy usage stretches beyond purely economic costs. Increasing numbers of international tourists and the growing hospitality sector has resulted in increased energy consumption, which has led to increased carbon dioxide emissions. For example, Turkey is becoming an increasingly popular tourist destination, attracting more than 30 million international tourists every year.[26] A 2014 study conducted by Professor Salin Turan Katircioglu investigated the long-run equilibrium relationship between tourism, energy

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[19] Williams, P., Leach, B., Christensen, K., Armstrong, G., Perrin, D., Hawkins, R., ... & Scholes, P. (2011). The composition of waste disposed of by the UK hospitality industry. *Banbury: Waste & Resources Action Programme (WRAP)*.
[20]Priani, 2016.
[21]Filimonau et al, 2018.
[22]U.S. department of energy. (n.d.) *Hospitality.* Better buildings. https://betterbuildingssolutioncenter.energy.gov/alliance/sector/hospitality
[23]ENERGYSTAR. (n.d.) *Hotels: An overview of energy use and energy efficiency opportunities.* https://www.energystar.gov/sites/default/files/buildings/tools/SPP%20Sales%20Flyer%20for%20Hospitality%20and%20Hotels.pdf
[24]U.S. Department of Energy.
[25]*Key resources and tools*. (n.d.) Better Buildings. U.S. department of energy. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Key_Energy_Resources_and_Tools_Hospitality_%20.pdf
[26]Katircioglu, S. T. (2014). International tourism, energy consumption, and environmental pollution: The case of turkey. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2014.04.058

consumption, and environmental degradation as shown by increasing carbon dioxide emissions in Turkey. The study found that there is a strong long-term equilibrium relationship between carbon dioxide emissions and its "determinants," like tourism.[27] The result also showed that increasing rates of tourism in Turkey led to significant carbon dioxide emissions and energy consumption, especially in the long-term, and that this effect continued to get stronger over time.[28] Thus, increasing energy efficiencies and use of renewable energy sources in the hospitality industry is likely both economically and environmentally beneficial.

Water is another key resource for hotels, thus hotels will benefit from improving the efficiency of use and contributing to its overall conservation. Water scarcity is a global issue, with demand for potable water–water that meets certain criteria and is labeled as safe for consumption–is projected to exceed availability by 40% by the year 2030.[29] Hotel companies have clear cost factors that highlight their need to address water usage in their buildings. On average, water accounts for 10% of utility costs in hotels. Furthermore, most hotel operations ultimately pay for the water used by their guests twice, once when the fresh water is initially purchased and then a second time when the water is disposed of.[30] In order to reduce their operational water usage, hotels around the world are taking different measures to improve efficiencies in their water consumption and reduce waste water. A Holiday Inn property in Flinders, Australia installed low-flow bathroom appliances in its guest rooms which decreased the property's water usage by 50% and resulted in the regaining of the hotel's initial $19,500 USD investment in only 18 months.[31] Other hotels are using consumer incentives to reduce water consumption. All Starwood hotel brands in the United States offer guests a $5 per day voucher to spend at the hotel to incentivize the guests to opt out of the room cleaning service.[32] Furthermore, the hospitality industry is beginning to explore the installation of greywater systems on their properties as they allow hotels to reduce their total water consumption by an average of 23 percent.[33] Greywater refers to water that has been previously in any water systems within a building other than in toilets. Greywater systems currently face significant

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[27] Katircioglu, 2014.
[28] Katircioglu, 2014.
[29] Tuppen, H. (2013, March 22). *Water management and responsibility in hotels.* Green hotelier. https://www.greenhotelier.org/know-how-guides/water-management-and-responsibility-in-hotels/
[30] Tuppen, 2013.
[31] Tuppen, 2013.
[32] https://www.greenhotelier.org/know-how-guides/water-management-and-responsibility-in-hotels
[33] Bruns-Smith, A., Choy, V., Chong, H., & Verma, R. (2015). Environmental sustainability in the hospitality industry: Best practices, guest participation, and customer satisfaction. *Cornell Hospitality Report*. https://scholarship.sha.cornell.edu/cgi/viewcontent.cgi?article=1199&context=chrpubs

barriers to implementation depending on the country as many countries have strict regulations around the reuse of greywater inside buildings as a health and safety precaution.[34]

II. The Potential of Green Architecture in the Hospitality Industry

Green architecture, also known as "green building technology" or "sustainable architecture," refers to buildings whose design and logistics are developed in alignment with environmentally friendly principles.[35] The goal of green architecture is to minimize the total resources consumed in a building's construction and use in order to diminish the building's negative environmental impact with factors including pollution, emissions, and waste.[36] The five major elements of green building design include: 1) sustainable site design, 2) water conservation and quality, 3) energy and environment, 4) indoor environmental quality, and 5) conservation of materials and resources.[37] Building with these principles of green architecture produces environmental, social, and economic benefits. Green architecture produces environmental benefits by reducing pollution, conserving natural resources, and preventing environmental degradation commonly felt with traditional architecture.[38] Green building produces economic benefits by reducing the total amount of money spent on the water and energy used in the building's operations while also improving the productivity of users of the building.[39] Additionally, green architecture produces social benefits as these buildings are designed to be aesthetically beautiful, more healthy for occupants, and minimally straining to the existing infrastructure.[40] Because of these benefits, green building technology has significant potential in the hospitality industry to reduce the environmental impact of various properties through both the new design and retrofitting of building systems resulting in decreased resource consumption and improved facility efficiencies.[41]

The concept of sustainability in the "built environment" is pushing more industries to focus on mitigating environmental impacts to achieve social, environmental, and even economic benefits. Studies have shown that some of the main driving factors of sustainable design and

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[34] Tuppen, 2013.

[35] Ragheb, A., El-Shimy, H., Ragheb, G. (2016). Green architecture: A concept of sustainability. *Procedia social and behavioral sciences.* https://doi.org/10.1016/j.sbspro.2015.12.075

[36] Ragheb et al, 2016.

[37] Ragheb et al, 2016.

[38] Ragheb et al, 2016.

[39] Ragheb et al, 2016.

[40] Ragheb et al, 2016.

[41] Bohdanowicz, P., Martinac, I. (2007). Determinants and benchmarking of resource consumption in hotels: A case study of hilton international and scandic in europe. *Energy and Buildings*. https://doi.org/10.1016/j.enbuild.2006.05.005

construction include energy conservation, indoor environmental quality improvements, environmental and resource conservation, and waste reduction.[42] While consumer interest in green hotel operations have varied in the past, green development is becoming a new expected norm by consumers using commercial buildings like hotels, especially as the costs of green technologies decline as technologies improve.[43] Changes in market demand for green hotels can be seen in studies such as in the National Leisure Travel Monitor survey, where 85 percent of leisure travelers consider themselves to be environmentally conscious travelers,[44] or in the J.D. Power and Associates North American Hotel Guest Satisfaction Study, where approximately 75 percent of all hotel guests stated that they were willing to participate in the hotel's environmentally friendly programs.[45] A study from the Cornell School of Hospitality on hotel guest's preferences for green guest rooms found that green certifications were the most influential factor for both business and luxury travelers on hotel room preferences.[46] Thus, there appears to be an expanding market opportunity for the hospitality industry to embrace and incorporate more green building technologies.

III. Barriers to Implementation

Although green building technologies are gaining popularity as a viable opportunity to meet the growing demand for environmentally friendly buildings, many significant barriers exist that could potentially slow or limit their adoption.[47] These barriers vary across different studies and highlight factors including economic concerns, like potentially long pay back periods from sustainable practices; attitudes towards new technologies, including stakeholders' resistance to change; and the need for specialized knowledge and skills to correctly implement green building technology systems.[48] However, the most significant barrier to sustainable design and construction is most frequently cited as the high initial cost premiums of green architecture projects.[49] One manner of addressing these cost-related problems is through government incentives that would make green architecture more affordable and thus more widely used.

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[42] Ahn et al, 2013.
[43] Butler, J. (2008). The compelling “hard case” for “green” hotel development. *Cornell university.* https://doi.org/10.1177/1938965508322174
[44] Millar, M., & Baloglu, S. (2011). Hotel guests' preferences for green guest room attributes. Cornell hospitality quarterly, 52(3), 302–311. https://doi.org/10.1177/1938965511409031
[45] Butler, 2008.
[46] Millar & Baloglu, 2011.
[47] Chan et al, 2016.
[48] Ahn et al, 2013.
[49] Chan et al, 2016.

These incentives should span not only active new construction and retrofitting costs but also be used to incentivize research and development of green products and technologies. Creating more credible research about the benefits of green building will help to increase public awareness of environmental issues that come with traditional building practices while also creating higher demands for green building technologies. Another manner of addressing these high upfront costs is to ensure the consideration of the long-term savings that these technologies will create over their total useful lives, like through an NPV analysis.

TECHNOLOGIES IN GREEN SOLUTION HOUSE

I. The On-Site Pyrolysis Plant

Green Solution House uses an in-house stationary pyrolysis plant to produce energy for the building from its food waste. According to the Green Solution House website, the pyrolysis system is “self-supporting and only requires a small amount of energy to start up.” [50] Food scraps and other organic materials are fed into the heating chamber of the pyrolysis plant. The material is dried and ground up, then the plant removes the oxygen from the chamber. The plant then heats the waste and breaks it down further, producing natural gas, bio-oil and biochar. These products are separated into two different service cycles for the hotel: 1) the biological cycle and 2) the electricity and heat cycle. The relationship between the two cycles is shown visually in Figure 3. The biochar sequesters carbon in a stable state while also serving as fertilizer for the restaurant vegetable garden on location at Green Solution House.[51] The natural gas and bio-oil are then combusted in the combined heat and power engine, resulting in the generation of thermal energy and electric energy for use in the building. Excess electricity that is not used by the hotel can be redistributed externally to the Bornholm energy grid.[52] Excess heat can be stored on-site as hot water in a repurposed swimming pool located below the restaurant’s kitchen floor. This thermal energy storage system has the capacity to store up to 80 liters of hot water and has two seasonally determined operational modes.[53] During the summer months, this system operates at a maintained temperature of 80 degrees Celsius (176 degrees Fahrenheit) and meets the total hotel need for heating and potable hot water. During the winter months, the storage system runs at a maintained temperature of 40 degrees Celsius

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[50] *The 75 green solutions.* (n.d.) Green Solution House. https://www.greensolutionhouse.dk/en/green-solutions-2/

[51] *The 75 green solutions.*

[52] *The 75 green solutions.*

[53] *The 75 green solutions.*

(104 degrees Fahrenheit) and is used for floor heating in the conference center and preheating potable hot water.[54] This heat can also be redirected into the pyrolysis plant to contribute to the drying of the organic material inputs.

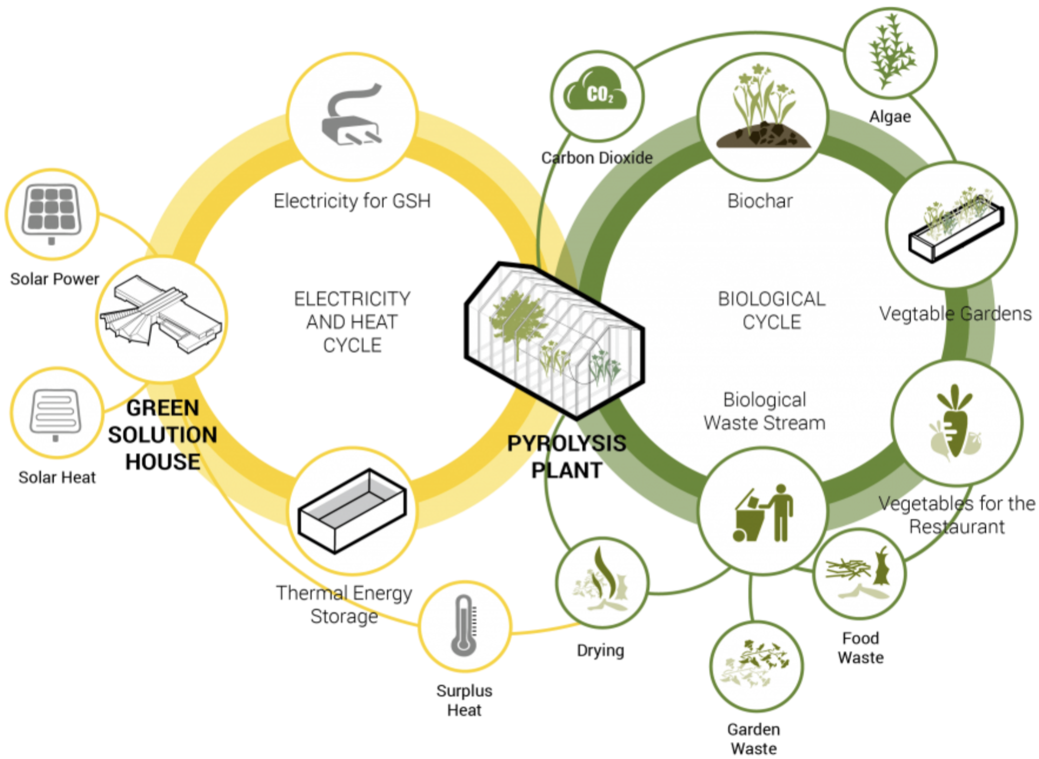

Figure 3: Pyrolysis Plant Infographic [55]

At its current capacity, Green Solution House produces approximately 12.4 tons of organic waste that can be used in the pyrolysis plant annually. The plant has the capacity to process one ton of dry material over six hours, resulting in the production of 180 m^3 of "gas," 360 kWh of electricity, and 100 kg of biochar.[56]

Pyrolysis plants are growing in popularity globally as they are associated with many environmental and efficiency benefits. Figure 4 shows a standard organic waste pyrolysis plant system from the biomass sector. Pyrolysis plants can replace coal and natural gas as viable fuel sources, leading to fewer greenhouse green emissions and less environmental

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[54] *The 75 green solutions.*
[55] Cradle to cradle, 2016.
[56] *The 75 green solutions.*

degradation.[57] Additionally, the pyrolysis process produces fewer air emissions than traditional incineration due to its limited use of oxygen. Furthermore, the air emissions that are created are easier to control because the plant can be cleaned after production to remove any leftover contaminants.[58] Pyrolysis plants are often flexible and easy to operate because they are modular systems made up of specific individual units and thus can have units added to or taken from the system depending on the changing mass of the organic matter system inputs.[59] However, pyrolysis systems also have potential challenges. The pyrolysis process could result in toxic minerals such as "inert mineral ash, inorganic compounds, and unreformed carbon" in addition to toxic air emission if the pyrolysis process is not fully completed. [60]

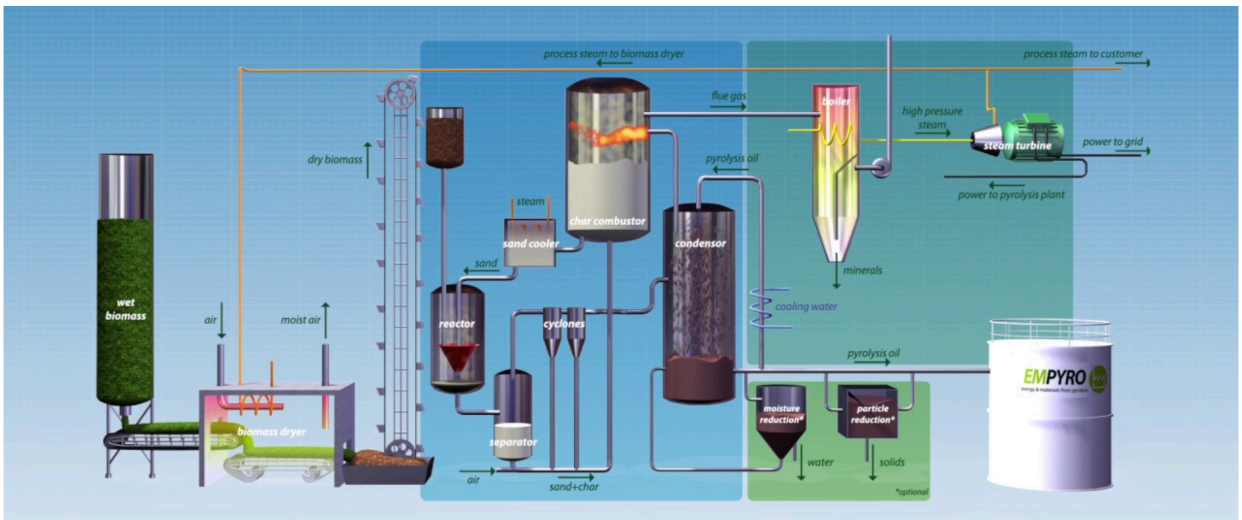

Figure 4: An Example of a Standard Organic Waste Pyrolysis Plant System[61]

Given the large amount of organic waste generated by the hospitality industry, pyrolysis plants are appropriate for use in hotels to turn this waste into a resource that is beneficial for the hotel. The addition of a pyrolysis plant to a hotel would decrease the costs surrounding waste removal while simultaneously decreasing the amount the hotel spends on electricity and heating costs.

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[57]Caruso, W., Sorenson, D., Mossa, A. (2006). Alternative energy technologies: High tech solutions for urban carbon reduction. *Worcester polytechnic institute.* https://web.wpi.edu/Pubs/E-project/Available/E-project-042506-065120/unrestricted/Technical_Report.pdf
[58]Caruso et al, 2006.
[59]Caruso et al, 2006.
[60]Caruso et al, 2006.
[61]*Empyro plant.* (2016). BTG bioliquids. https://i.ytimg.com/vi/od_JGRJC8zI/maxresdefault.jpg

II. Building Integrated Photovoltaic Panels

Green Solution House uses integrated photovoltaic panels to collect solar energy and maximize daylight while adding to the overall aesthetic and design of the building. Building integrated photovoltaic solar panels (BIPVs) differ from traditional solar panels as the photovoltaics are incorporated directly into the design of the building rather than being a separate addition to the building's construction. This allows the photovoltaic panels to both reduce the amount of conventional building material needed for the building envelope and separate photovoltaic system parts while also serving as a source for clean power generation.[62] According to the Whole Building Design Guide, "by avoiding the cost of conventional materials, the incremental cost of photovoltaics is reduced and its life-cycle cost is improved," thus BIPV systems often have lower long-term costs than traditional photovoltaic systems that require separate, dedicated, mounting systems.[63]

Green Solution House has incorporated BIPVs into the hotel's design in the form of VELUX modular skylights and solar balconies. The use of BIPVs was important to Green Solution House in order to maintain the "integrity of the minimalist Scandinavian design" while also utilizing green building technologies to increase the hotel's energy efficiency.[64] Green Solution House has a total of 68 VELUX modular skylights that have been fitted with integrated photovoltaic panels in order to maximize daylight while simultaneously capturing solar energy, thus reducing the total electric needs of the building. This cumulative 98 m^2 of photovoltaics in the rooftop skylights produce approximately 7,077 kWh of electricity per year, enough energy to power two average Bornholm homes for a full year.[65] Additionally, the balconies of the guest rooms on the south facing facade of the building are made of glass barriers with integrated photovoltaic panels that collect solar energy while also allowing for significant daylight to enter into the guest rooms. These solar balconies produce a total of 5,000 kWh of energy annually for the hotel.[66]

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[62]Strong, S. (2016, October 19). Building integrated photovoltaics. *Whole building design guide.* https://www.wbdg.org/resources/building-integrated-photovoltaics-bipv
[63]Strong, 2016.
[64]*Exploring circular sustainability*, 2015.
[65]*The 75 green solutions.*
[66]*The 75 green solutions.*

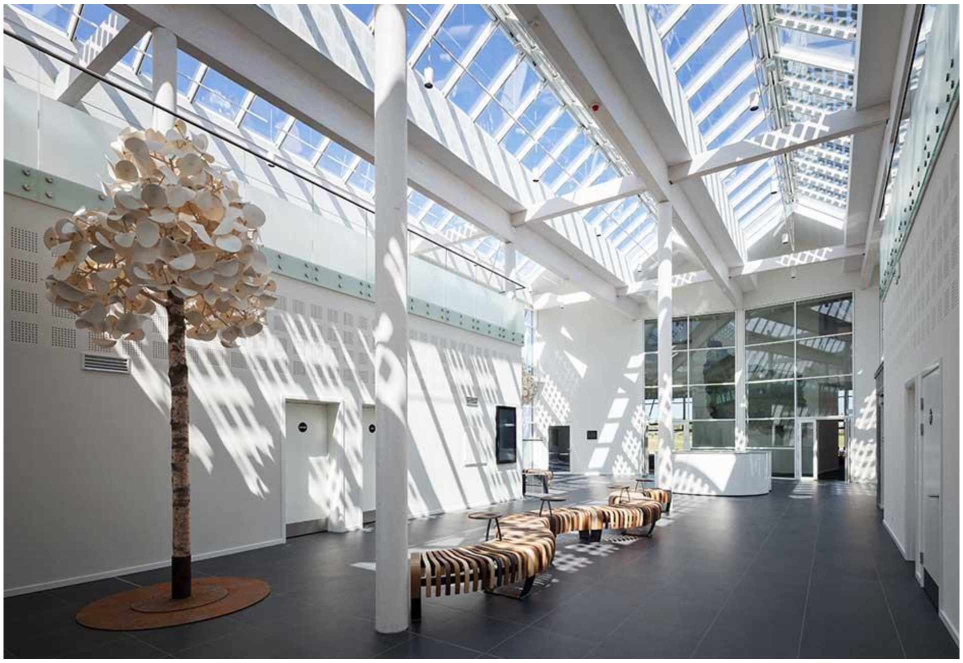

Figure 5: Main Lobby of Green Solution House[67]

Figure 6: A Solar Balcony Off of A Guest Room in Green Solution House[68]

[67] VELUX Commercial. (n.d.) *Green solution house: A sustainable hotel with modular skylights.* https://commercial.velux.com/inspiration/case-study/green-solution-house
[68] *The 75 green solutions.*

Including building integrated photovoltaic panels can provide many potential benefits to buildings. BIPVs are viewed as being more aesthetically appealing than other conventional building technologies as they can be designed and utilized in a multitude of ways, resulting in the ability of the design to create different visual effects while simultaneously making the building more environmentally friendly.[69] While BIPVs are extremely suitable to newer buildings given they can be more closely integrated into the building itself, the cost of retrofitting these technologies to existing buildings has been decreasing in recent years. Additionally, BIPVs can reduce heat gain in buildings during warmer months by preventing the interior of the building from being directly exposed to solar radiation while still allowing for passive daylight to enter, which reduces the work of the cooling system to maintain the desired temperature.[70]

Figure 7: Building Integrated Photovoltaic Panels in the Main Lobby Skylights at Green Solution House[71]

[69] Ng, P. K., Mithraratne, N. (2014). Lifetime performance of semi-transparent building-integrated photovoltaic glazing systems in the tropics. *Renewable and sustainable energy reviews*. https://doi.org/10.1016/j.rser.2013.12.044
[70] Ng, 2014.
[71] VELUX Commercial.

Although Green Solution House had not published any specific data on the performance of its integrated photovoltaic systems, BIPV systems have recently begun to appear in more studies and analyses. One study conducted on building integrated photovoltaic panels in Singapore examined the environmental and economic performance of the life cycle of commercially available semi-transparent BIPVs.[72] The study conducted a life cycle assessment to determine the long-term performance of the BIPV system in terms of cost considerations and energy and carbon emissions. The study concluded that the Energy Returned on Energy Invested (EROEI) for the BIPV modules was between 11.72 to 34.49.[73] EROEI is the ratio of energy outputs versus energy inputs that an energy source produces during its life cycle. The energy source is cheaper and easier to access if the EROEI number is larger and the modern societal energy "break-even" point number to hit is 7.[74] As the findings from this study report an EROEI of 11.72 and greater, the BIPV modules in this study are worth investing in depending on the needs of the building. Furthermore, the energy payback time (EPBT) for the modules examined in this study ranged from 0.68 to 1.98.[75] EPBT refers to the amount of time the module must produce power in order to make up for the power that was used in the construction of the module.[76] The BIPV modules in this study have an average EPBT of seven months to two years, which is significantly lower than the industry average of traditional photovoltaic panels at an EPBT range of two to five years.[77]

BIPV modules are a good fit for hotel usage because hotels are, by nature, very energy-intensive in their operations. Incorporating BIPVs into hotel properties will provide hotels with a green energy source that will decrease their electricity costs by generating clean, on-site energy.

III. Biological Water Purification Generators

All of the water from the sink, showers, and toilets in Green Solution House is collected and refined through an on-site biological water purification system. This system uses the natural processes of anaerobic and biological filtering stages to allow for the processing,

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[72] Ng, 2014.
[73] Ng, 2014.
[74] Conca, J. (2015, February 11). EROI: A tool to predict the best energy mix. *Forbes.* https://www.forbes.com/sites/jamesconca/2015/02/11/eroi-a-tool-to-predict-the-best-energy-mix/#9a074b0a0270
[75] Ng & Mithraratne, 2014.
[76] Gessert, T. A. (2012). Photovoltaic solar energy. *ScienceDirect.* https://www.sciencedirect.com/topics/engineering/energy-payback-time
[77] Gessert, 2012.

treatment, and on-site reuse of the hotel's wastewater.[78] The first stage of wastewater purification takes place below ground, where the wastewater sits in an anaerobic digestion stage.[79] The wastewater is then pumped into the two "Earth Lung" landscapes behind the building. This process acts as a "natural deodorizer" as it removes the "odorous biogases" by sending the wastewater through planter boxes that turn the biogas into fertilizer for the plants.[80] The water flows back into the building through six algae generator tubes, shown in Figure 8, where algae feeds on the nutrients and carbon dioxide present in the wastewater with assistance from sunlight and LED lighting built into the generators.[81] These six algae tubes can hold four times that daily wastewater used in the hotel.[82] Each of the six tubes has a steel base that contains the mineral "zeolite," which acts as a microbial filter in the water purification process that absorbs the microorganisms that are not broken down by the algae.[83]

Figure 8: Algae Generators in Green Solution House's Biological Water Purification System[84]

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[78]*Exploring circular sustainability*, 2015.
[79]*Exploring circular sustainability*, 2015.
[80]*The 75 green solutions.*
[81]*Exploring circular sustainability*, 2015.
[82]*The 75 green solutions.*
[83]*The 75 green solutions.*
[84]*The 75 green solutions.*

After the water leaves the algae generators, it is further purified by UV light to reach drinking level water quality standards.[85] However, as there are legal limitations and regulations as to how recycled water can be used inside buildings, Green Solution House is unable to currently close the water loop by recycling the water back into the hotel water supply.[86] Instead, the purified water is used for irrigation of the "living" Green Wall and the gardens. The Green Wall system is significantly sized, standing at 55 meters-squared or just under 600 feet-squared.[87] The system as a whole can process 500 liters of water daily. Green Solution House is currently working to obtain legal permission to establish a trial of using this purified water in the public toilets but has yet to receive permission.[88] The cumulative biological water purification system depicted in Figure 9.

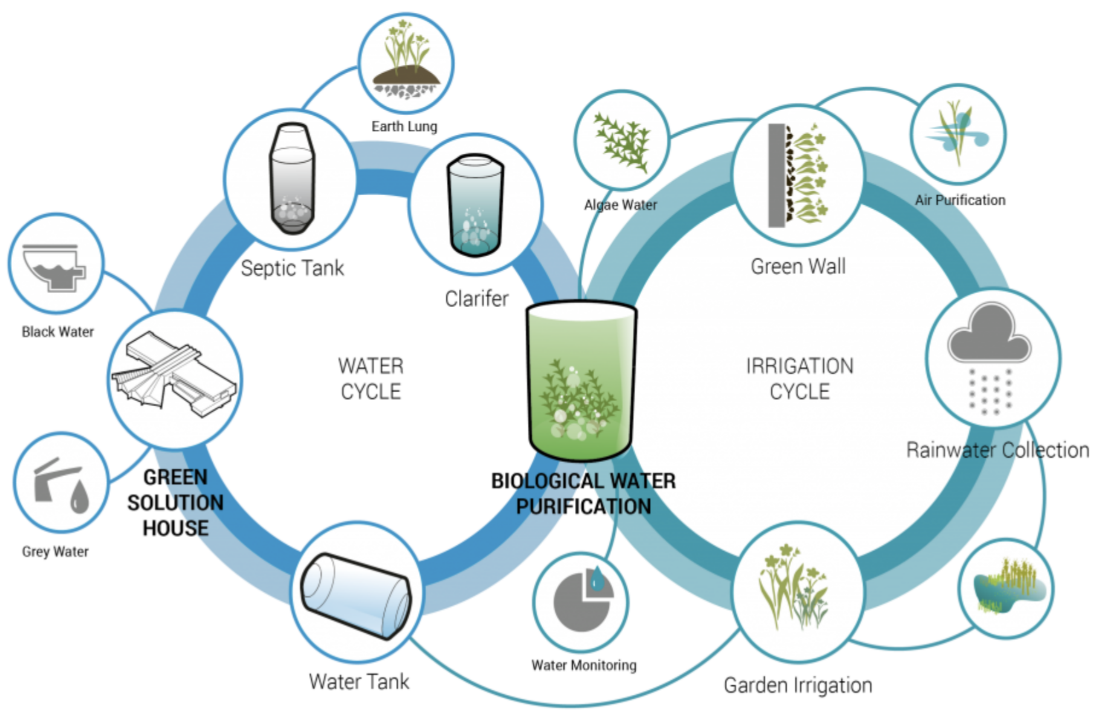

Figure 9: Biological Water Purification System Infographic [89]

[85] *The 75 green solutions.*
[86] *The 75 green solutions.*
[87] *The 75 green solutions.*
[88] *Recycling water from sinks and toilets with biological water purification*. (n.d.) State of green. https://stateofgreen.com/en/partners/green-solution-house/solutions/water-cycle/
[89] Cradle to cradle, 2016.

Recycling wastewater through a natural, biological purification method greatly reduces the total water consumption in hotels. Technological solutions that mimic naturally occurring processes are often found to be the most effective and least harmful solutions. The use of microalgae for wastewater treatment is being increasingly explored because microalgae can breakdown harmful water pollutants like nitrogen, oxygen, heavy metals, and various toxic organic compounds and will not lead to any form of secondary pollution.[90]

Academic studies are further exploring potential challenges and opportunities in using microalgae for the treatment of wastewater. Cultivating microalgae has gained some popularity due to its ability to photosynthesize carbon dioxide and to survive in different compositions of wastewater systems.[91] One study that reviewed the potential for the use of the microalgae "Chlorophyta" found that the algae could have viable uses in wastewater treatment in domestic or commercials settings; however, it would not be as successful in industrial applications because the heavy metal and high organic demand in the nutrient removal process is significantly higher and thus would need the assistance of "growth enhancers" to support the Chlorophyta's continued growth in the industrial wastewater.[92] As hotels fall into the commercial categorization of wastewater, such developments in water purification could help hotels reduce their total water consumption by reusing purified greywater in their operations.

Even after the wastewater is treated, there are currently significant legal restrictions as to how treated greywater can be used inside buildings that vary by country. However, as water scarcity is becoming an increasingly threatening issue on a global scale, the reuse of greywater is an important water management approach that should not be overlooked.[93] In order to promote the increased reuse of greywater globally, countries need to create clear and cohesive standards for greywater use inside buildings.[94] Policies need to be developed to help build public acceptance for the reuse of recycled water by focusing on public safety and the potential benefits to reduce any existing stigma or "yuck factor" around water treatment and reuse. Cities such as Windhoek, Namibia should be used as a leading example of water recycling.

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[90]Abdel-Raouf, N., A;-Homaidan, A. A., Ibraheem, I. B. M., (2012). Microalgae and wastewater treatment. *Saudi journal of biological sciences*. https://doi.org/10.1016/j.sjbs.2012.04.005

[91]Abhinandan, S., Shanthakumar, S. (2015). Challenges and opportunities in application of microalgae (Chlorophyta) for wastewater treatment: A review. *Renewable and sustainable energy reviews.* https://doi.org/10.1016/j.rser.2015.07.086

[92]Abhinandan & Shanthakumar, 2015.

[93] Vuppaladadiyam, A. K., Merayo, N., Prinsen, P., Luque, R., Blanco, A., & Zhao, M. (2019). A review on greywater reuse: quality, risks, barriers and global scenarios. *Reviews in environmental science and biotechnology.* https://doi.org/10.1007/s11157-018-9487-9

[94]Vuppaladadiyam et al, 2019.

Windhoek has been reusing potable water since 1968 due to the scarcity of available water in the region.[95] In the 1990s, the government committed to building a wastewater facility that could meet the growing water needs of the city. The government opened the New Goreangab Water Reclamation Plant in 2002 that could operate at an increase of 4.5 times the capacity of the original facility. In 2010, the Windhoek government commissioned a public survey on residents' satisfaction with water and found that, while the respondents were "largely satisfied" with the water quality they received, many city residents did not know that their water was being recycled.[96] Windhoek went on to invest in public awareness campaigns that celebrated the city's water reuse program that resulted in low "yuck factor" or negative sentiment about the waster reuse program moving forward.[97] This example highlights how governments can promote green technologies to help increase public awareness and acceptance of these technologies.

Increased public acceptance of greywater reuse and increased implementation of greywater systems will greatly benefit the hotel industry as hotels use significant amounts of water in their operations–from the showers and sinks in guest rooms to the kitchens and laundry facilities. By implementing a system that allows for this greywater to be captured, purified, then used again in hotel toilets, the hospitality industry as a whole will be able to significantly decrease its total water consumption.

FINANCIAL ANALYSIS

The financial analysis in this paper will be completed using a net present value analysis of the pyrolysis plant and the building integrated photovoltaic panels. Net present value (NPV) is the value of a future cash flows over the useful life of an investment discounted to the present.[98] Cash flows must be discounted at an assumed rate of return to adjust for risk in an investment and to account for the time value of money, which is the idea that a dollar today is worth more than a dollar in the future.[99] NPV was chosen for this analysis as it is a commonly used valuation method that businesses implement to evaluate investment opportunities. The NPV analyses for these green building technologies will show if the initial investment and

[95]Hartley, K., Tortajada, C., Biswas, A. K. (2019). A formal model concerning policy strategies to build public acceptance of potable water reuse. *Journal of environmental management*. https://doi.org/10.1016/j.jenvman.2019.109505
[96]Harley et al, 2019.
[97]Harley et al, 2019.
[98]*Corporate finance institute*. (n.d.) Net present value. https://corporatefinanceinstitute.com/resources/knowledge/valuation/net-present-value-npv/
[99]*Corporate finance institute*.

subsequent cash flows received in these projects generate a positive or negative expected rate of return. If the NPV of these technologies is negative, it means that the project does not create the desired return on investment and will result in a net loss; however, if the NPV is positive, the investment is assumed to be profitable and will create value.[100]

I. Pyrolysis Plant

Currently, Green Solution House produces 12.4 tons of organic waste annually that is usable in the pyrolysis plant, which results in an output of 180 meters cubed (m^3) of natural gas used for heating, 360 kilowatt-hours (kWh) of electricity, and 100 kilograms (kg) of biochar used as fertilizer in the kitchen gardens. The plant, however, has the capacity to handle a total of 1,460 tons of organic waste annually and thus is currently operating at a significantly lower level than its potential.[101] The initial cost of a pyrolysis plant of this capacity is $55,600 USD and has a useful life of ten years.[102] For the purposes of this analysis, the value of natural gas was estimated to be $1.02 per meter-cubed,[103] the value of electricity was estimated to be $0.32 USD per kWh,[104] and the value of biochar was estimated to be $0.09 per kg.[105] The current output of 12.4 annual tons results in total benefits equal to $3,816.72 USD annually. Using a standard hurdle rate of 5%, this results in a negative NPV for the pyrolysis plant of -$26,128.30 USD. This negative NPV shows that, at the current usage rates of the plant, the pyrolysis plant is not worth the initial $55,600 investment. These calculations are shown in Figure 10.

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[100] *Corporate finance institute*.
[101] *The 75 green solutions.*
[102] Guo, G. (2020, April 23). Email, personal interview. *Beston Machinery Co.*
[103] *Electricity and natural gas prices.* (2019). Statistics denmark. https://www.dst.dk/en/Statistik/emner/geografi-miljoe-og-energi/miljoe-og-energi/el-og-naturgaspriser
[104] *Denmark electricity prices.* (2019, September). Global Petrol Prices. https://www.globalpetrolprices.com/Denmark/electricity_prices/
[105] Bruckman, V. J., Varol, E. A., Uzun, B. B., Liu, J. (2016). Biochar: A regional supply chain approach in view of climate change mitigation. *Cambridge university press.*

Base Case (annual tons produced)		**12.4**
Initial Cost	$	55,600
Plant Useful Life (years)		10
Hurdle Rate		5%
Gas Produced (m3)		2232
Value of Gas ($/m3)	$	1.02
Electricity Produced (kWh)		4464
Value of Electricity ($/kWh)	$	0.32
Biochar Produced (kg)		1240
Value of Biochar ($/kg)	$	0.09
Total Benefits	**$**	**3,816.72**
Cash Flows		
Year 0	$	(55,600)
Year 1	$	3,816.72
Year 2	$	3,816.72
Year 3	$	3,816.72
Year 4	$	3,816.72
Year 5	$	3,816.72
Year 6	$	3,816.72
Year 7	$	3,816.72
Year 8	$	3,816.72
Year 9	$	3,816.72
Year 10	$	3,816.72
Net Present Value	**$**	**(26,128.30)**

Figure 10: Pyrolysis Plant Base Case NPV Calculations

Although this machine is not currently operating at a capacity that results in a positive NPV, the plant has the potential capacity to reach a positive NPV if more inputs (tons of organic waste) were used annually. Using this maximum capacity in the same calculations as before results in total annual benefits of $449,388 USD and a positive NPV of $3,414,455.02 USD.[106] This large, positive NPV value shows that the pyrolysis plant used at maximum capacity is a beneficial investment for Green Solution House. These calculations are shown in Figure 11.

[106] *The 75 green solutions.*

Max Capacity Case (annual tons produced)	**1460**
Initial Cost	$ 55,600
Plant Useful Life (years)	10
Hurdle Rate	5%
Gas Produced (m3)	262800
Value of Gas ($/m3)	$ 1.02
Electricity Produced (kWh)	525600
Value of Electricity ($/kWh)	$ 0.32
Biochar Produced (kg)	146000
Value of Biochar ($/kg)	$ 0.09
Total Benefits	**$ 449,388.00**
Cash Flows	
Year 0	$ (55,600)
Year 1	$ 449,388.00
Year 2	$ 449,388.00
Year 3	$ 449,388.00
Year 4	$ 449,388.00
Year 5	$ 449,388.00
Year 6	$ 449,388.00
Year 7	$ 449,388.00
Year 8	$ 449,388.00
Year 9	$ 449,388.00
Year 10	$ 449,388.00
Net Present Value	**$ 3,414,455.02**

Figure 11: Pyrolysis Plant Maximum Capacity Case NPV Calculations

It would be difficult for Green Solution House to expand from its current states of 12.4 tons of organic waste produced annually to the generation of 1,460 tons of organic waste; however, to reach a break-even NPV of zero, only approximately 23.39 tons of organic waste need to be created annually as shown in Figure 12. Thus, for the pyrolysis plant to be a financially worthwhile investment for the hotel, Green Solution House must find a way to increase the amount of organic waste they feed into the plant by a minimum of approximately 11 tons. While this is nearly double the current organic waste generation of the hotel itself, by partnering with the surrounding Bornholm government and community, this should be a relatively easy increase to achieve.

Break Even Case (annual tons produced)		23.39329
Initial Cost	$	55,600
Plant Useful Life (years)		10
Hurdle Rate		5%
Gas Produced (m3)		4210.7922
Value of Gas ($/m3)	$	1.02
Electricity Produced (kWh)		8421.5844
Value of Electricity ($/kWh)	$	0.32
Biochar Produced (kg)		2339.329
Value of Biochar ($/kg)	$	0.09
Total Benefits	**$**	**7,200.45**
Cash Flows		
Year 0	$	(55,600)
Year 1	$	7,200.45
Year 2	$	7,200.45
Year 3	$	7,200.45
Year 4	$	7,200.45
Year 5	$	7,200.45
Year 6	$	7,200.45
Year 7	$	7,200.45
Year 8	$	7,200.45
Year 9	$	7,200.45
Year 10	$	7,200.45
Net Present Value	**$**	**0.00**

Figure 12: Pyrolysis Plant Break Even Case NPV Calculations

In order for Green Solution House to feed more organic waste into its pyrolysis plant, the hotel needs to import waste from beyond its facilities. Luckily, the hotel is positioned in the perfect location as the island of Bornholm and its residents have already made significant sustainability commitments, including a commitment to become a "garbage-free" island by 2032.[107] The island of Bornholm is 227 square miles and is home to 40,000 permanent residents and hosts 600,000 annual visitors. The local government has already adopted a strategy called "Bright Green Island" that seeks to position Bornholm as a leader in sustainable development, with commitments like becoming carbon neutral by 2025, converting to 100 percent green energy sources, and expanding the island's organic farmlands.[108]

According to Bornholms Affaldsbehandling (BOFA), the island's waste management company, approximately 39 percent of household waste is currently recycled while the rest is incinerated and Bornholm residents currently pay a waste disposal tax of $454 USD annually for all waste management services.[109] The island has one incineration plant that is coming to the end of its useful life and is in the process of being shut down as the island transitions to

[107] Gunn, K. (2019, April 22). This island is going trash free—by recycling all of its waste. *National Geographic*. https://www.nationalgeographic.com/environment/2019/04/bornholm-island-denmark-goes-trash-free-by-recycling/
[108] Gunn, 2019.
[109] Gunn, 2019.

becoming waste-free. While recycling programs have already been widely adopted and will be expanded to include more materials, the question remains of what to do with materials such as organic waste that were previously easier to incinerate. BOFA Chief Executive Officer Jens Hjul Nielsen has been quoted on the logistics of transition to a more circular economy stating that, “by 2032 we aim to reuse or recycle everything. How we get to that point is an exciting process, because there is so much we don’t yet know. We have a vision, but no clear-cut plan on how to get there.”[110] In compliance with a nationwide policy, by 2022, 50 percent of household waste must be sorted into seven categories for recycling as follows: paper, plastic, cardboard, wood, metal, glass, and food. This has led to the local government's approval of a 15 percent increase in Bornholm resident’s waste disposal tax, adding $68 USD to the current $454 USC tax to result in a new waste disposal tax of $522 per household.[111] Any residual waste that BOFA is unable to recycle will have to be sent off the island to be incinerated at a different facility.

In order to make this transition successful, BOFA is looking to engage the private sector in projects that help the island to go waste-free. BOFA should look to partner with Green Solution House to send all sorted food waste to the hotel. This would be beneficial to BOFA as Green Solution House is located 5.4 kilometers (less than 3.4 miles) from their facilities, thus it would likely be more cost effective to drive their organic waste to the hotel rather than to pay to export this waste to a different waste management facility off of the island. This partnership would also be beneficial for Green Solution House by providing the hotel with the needed additional tons of organic waste so that the pyrolysis plant can operate at a capacity resulting in a positive NPV. This is one example of how partnerships between the private and public sectors can lead to mutual cost saving and sustainability as pyrolysis plants are just one of green building technologies that can function effectively at the district of urban scale.

II. Integrated Photovoltaic Panels

Green Solution House has a total of 116 BIPV modules across the skylights and solar balconies, each of which is estimated to cost approximately $800 USD, resulting in a total cost of $92,800 USD. These modules are estimated to have a useful life of 30 years. The entire system captures approximately 12,077 kWh of electricity annually. Using the same value of electricity as the pyrolysis plant NPV calculations of $0.32 USD, the total benefits produced by the BIPV modules equates to $3,864.64 USD annually.[112] Using a standard hurdle rate of 5%,

[110]Gunn, 2019.
[111]Gunn, 2019.
[112]*Denmark electricity prices,* 2019.

this results in a negative NPV for the BIPV system of -$33,391.01 USD. This negative NPV shows that, at the current solar capture rates of the modules, the BIPV modules are not worth the initial $92,800 USD investment. These calculations are shown in Figure 13.

Base Case (annual kWh produced)		**12077**
BIPV Module Useful Life (years)		30
Hurdle Rate		5%
Initial Cost per BIPV Module	$	800.00
Number of BIPV Modules		116
Total Cost	**$**	**92,800**
Electricity Produced from Balconies (kWh)		5000
Electricity Produced from Skylights (kWh)		7077
Value of Electricity ($/kWh)	$	0.32
Total Benefits	**$**	**3,864.64**
Cash Flows		
Year 0	$	(92,800)
Year 1	$	3,864.64
Year 2	$	3,864.64
Year 3	$	3,864.64
Year 4	$	3,864.64
Year 5	$	3,864.64
Year 6	$	3,864.64
Year 7	$	3,864.64
Year 8	$	3,864.64
Year 9	$	3,864.64
Year 10	$	3,864.64
Year 11	$	3,864.64
Year 12	$	3,864.64
Year 13	$	3,864.64
Year 14	$	3,864.64
Year 15	$	3,864.64
Year 16	$	3,864.64
Year 17	$	3,864.64
Year 18	$	3,864.64
Year 19	$	3,864.64
Year 20	$	3,864.64
Year 21	$	3,864.64
Year 22	$	3,864.64
Year 23	$	3,864.64
Year 24	$	3,864.64
Year 25	$	3,864.64
Year 26	$	3,864.64
Year 27	$	3,864.64
Year 28	$	3,864.64
Year 29	$	3,864.64
Year 30	$	3,864.64
Net Present Value	**$**	**(33,391.01)**

Figure 13: BIPV Base Case NPV Calculations

Unlike with the pyrolysis plant, the successes of BIPV systems are extremely dependent on place. It is difficult to increase the total amount of kWh captured annually by the BIPV module system as there is a fixed amount of sunlight in any specific location. In the case of Green Solution House, the location is fixed to its existing state. Assuming these modules have all been placed in the optimal direction for maximum solar capture, there is no way to increase the amount of energy the system can capture. However, these BIPV modules could achieve a positive NPV if the costs were subsidized. By reducing the total costs from $800 USD per module to $512.15 USD per module, the NPV of the BIPV system goes from negative to zero. Thus, if the cost of each module was less than $512.15 USD, the investment in the system would generate a positive NPV and be financially viable.

Subsidized Case (annual kWh produced)		**12077**
BIPV Module Useful Life (years)		30
Hurdle Rate		5%
Initial Cost per BIPV Module	$	512.15
Number of BIPV Modules		116
Total Cost	**$**	**59,409**
Electricity Produced from Balconies (kWh)		5000
Electricity Produced from Skylights (kWh)		7077
Value of Electricity ($/kWh)	$	0.32
Total Benefits	**$**	**3,864.64**
Cash Flows		
Year 0	$	(59,409)
Year 1	$	3,864.64
Year 2	$	3,864.64
Year 3	$	3,864.64
Year 4	$	3,864.64
Year 5	$	3,864.64
Year 6	$	3,864.64
Year 7	$	3,864.64
Year 8	$	3,864.64
Year 9	$	3,864.64
Year 10	$	3,864.64
Year 11	$	3,864.64
Year 12	$	3,864.64
Year 13	$	3,864.64
Year 14	$	3,864.64
Year 15	$	3,864.64
Year 16	$	3,864.64
Year 17	$	3,864.64
Year 18	$	3,864.64
Year 19	$	3,864.64
Year 20	$	3,864.64
Year 21	$	3,864.64
Year 22	$	3,864.64
Year 23	$	3,864.64
Year 24	$	3,864.64
Year 25	$	3,864.64
Year 26	$	3,864.64
Year 27	$	3,864.64
Year 28	$	3,864.64
Year 29	$	3,864.64
Year 30	$	3,864.64
Net Present Value	**$**	**0.00**

Figure 14: BIPV Subsidized Case NPV Calculations

The Danish government is currently trying to expand the use of solar energy across the country. In 2018, the government signed an energy agreement strengthening Denmark's climate and energy goals. By 2030, Denmark aims to source 55 percent of the country's total energy needs from renewable sources; furthermore, Denmark aims to be completely fossil fuel independent by 2050.[113] A key element of this agreement includes increasing available funding to incentivize the expansion of solar energy technologies. "From 2021 to 2024, EUR 67 million ($73.4 million USD) will be allocated annually to a market-based grant pool focused on energy savings–EUR 40 million ($43.8 million USD) for industries and EUR 27 million ($29.6 million USD) for energy savings in buildings."[114] If such grants and subsidies were available to Green Solution House at the time of the initial investment, they would have reduced the initial cost of the BIPV modules, allowing for Green Solution House to achieve a positive NPV for its investment.

Furthermore, the BIPV system could be a profitable investment if this same system was implemented in a different geographic location that had more annually available sunlight. In order for this existing system to be financially viable, the location of the system has to allow for more than 18,864.917 kWh of solar energy to be captured annually. This calculation is shown in Figure 15.

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[113] *Ministry of foreign affairs of denmark.* (2018, June 5). New ambitious danish energy agreement secured. Invest in denmark. https://investindk.com/insights/new-ambitious-danish-energy-agreement
[114] *Ministry of foreign affairs of denmark.*

New Location Case (annual kWh produced)	**18864.917**
BIPV Module Useful Life (years)	30
Hurdle Rate	5%
Initial Cost per BIPV Module	$ 800.00
Number of BIPV Modules	116
Total Cost	**$ 92,800**
Total Electricity Produced (kWh)	18864.917
Value of Electricity ($/kWh)	$ 0.32
Total Benefits	**$ 6,036.77**
Cash Flows	
Year 0	$ (92,800)
Year 1	$ 6,036.77
Year 2	$ 6,036.77
Year 3	$ 6,036.77
Year 4	$ 6,036.77
Year 5	$ 6,036.77
Year 6	$ 6,036.77
Year 7	$ 6,036.77
Year 8	$ 6,036.77
Year 9	$ 6,036.77
Year 10	$ 6,036.77
Year 11	$ 6,036.77
Year 12	$ 6,036.77
Year 13	$ 6,036.77
Year 14	$ 6,036.77
Year 15	$ 6,036.77
Year 16	$ 6,036.77
Year 17	$ 6,036.77
Year 18	$ 6,036.77
Year 19	$ 6,036.77
Year 20	$ 6,036.77
Year 21	$ 6,036.77
Year 22	$ 6,036.77
Year 23	$ 6,036.77
Year 24	$ 6,036.77
Year 25	$ 6,036.77
Year 26	$ 6,036.77
Year 27	$ 6,036.77
Year 28	$ 6,036.77
Year 29	$ 6,036.77
Year 30	$ 6,036.77
Net Present Value	**$ 0.00**

Figure 15: BIPV New Location Case NPV Calculations

The total amount of energy that photovoltaic panels can capture is extremely dependent on location. Based on Denmark's global coordinates, the country as a whole receives less solar energy annually than other countries. Since solar energy is fixed based on location, Green Solution House can only capture a fixed total amount of solar energy. Photovoltaic modules will capture more solar energy in countries with more solar energy potential, which will translate into increasing annual benefits for the region's hotels. Thus, if this same system was implemented in a geographic location that had greater solar energy available, the investment in the system could become profitable. Figure 16 shows the average solar energy potential of different countries and regions globally. Based on this map, countries in the southern hemisphere, in general, have a higher solar energy potential than the countries in the northern hemisphere. It is likely that hotels in countries with such high levels of capturable solar energy would generate profits through investment in green technologies like BIPV panels; however, the capacities of BIPV modules should still be analyzed at the individual property level. Furthermore, as large hotel corporations operate across vastly different geographic locations, it could be possible for these companies to create an internal subsidy program that allows for the profits generated by BIPV systems in one location to offset the costs of implementing BIPVs on a different property.

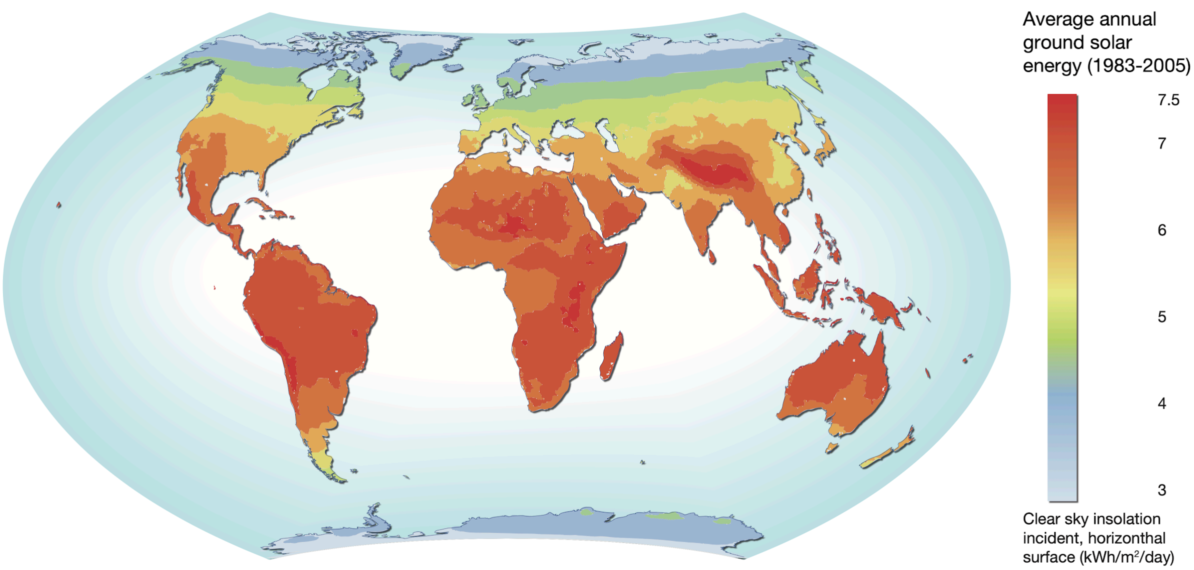

Figure 16: Global Map of Average Potential Solar Energy Accessible at Ground Level[115]

LIMITATIONS

As a method for gauging an investment's profitability, NPV analyses have some drawbacks. An NPV analysis relies on assumptions and estimates, including the investment costs, discount rate, and projected returns, thus there is room for assumption and estimation errors. Furthermore, NPV is solely an economic valuation method and does not account for other non-monetary considerations. Buildings do not exist as truly independent systems as the built environment can have significant impacts on the larger, surrounding system. Thus, it is argued that businesses should be held responsible for externalities that are not traditionally included in cost accounting. Implementing green building technologies can result in

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[115]United Nations Environmental Programme. (2008). *NASA surface meteorology and solar energy.* https://www.grida.no/resources/7308

environmental benefits not captured in a financial analysis, such as the non-use value of lower carbon emissions, reduced water consumption, and less land degradation. Green building technologies can also bring social benefits to hotels by creating healthier buildings for occupants. By creating aesthetically interesting and socially conscious built environments, hotels can become destinations themselves. By marketing these green technologies effectively, hotels can differentiate themselves from competitors, creating a competitive advantage that will benefit the company as the trend of consumer demand toward green building standards continues to grow. Furthermore, as governments continue to pass restrictions around increasing renewable energy usage or decreasing emission outputs, incorporating green building technologies can help businesses stay ahead of these changing requirements.

CONCLUSION

Green building technologies have the potential to significantly decrease the environmental impact of the hospitality industry. However, in order to be implemented, hospitality companies will be looking for a return on their investment. Financial analyses like NPV is one way businesses look to make decisions. This gives companies important economic validation for investments, but is not a holistic measure of other non-financial benefits a company may receive. Furthermore, some green building technologies will be easier to implement and more economically viable than others. On-site biological water purification systems are currently the most difficult to implement as the technologies are still being researched and developed. Additionally, many countries have strict regulations around how recycled water can be used inside buildings, limiting the potential adoption of these technologies even if they were more advanced. Pyrolysis plants have huge future potential for the hospitality industry as hotels generate a significant amount of food and organic waste and require lots of energy in their operations; however, hotels need to ensure that they have the capacity to produce a certain minimum level of organic waste materials to feed into the plants to make their investments worthwhile. Integrated photovoltaic panels are likely the most feasible green building technologies that hotels should look to incorporate into their operations as the technologies exist at a commercial level and there is significant research available about the productivity of different systems. However, hotels in different geographical areas will be able to collect varying levels of energy from these systems, thus the implementation of BIPVs needs to be evaluated at the individual property levels.

Further research should be done regarding the potential of green building technologies in hospitality in reference to the varying initiatives and priorities of different countries. Countries around the globe have different goals surrounding sustainability commitments. Some countries have enacted policies or have created subsidies that incentives green architecture, thus allowing for the faster adoption of these technologies. Furthermore, as the successes of green building technologies such as BIPV modules are very reliant on the building's location and climate, it would be interesting to see in which countries green architecture is the most feasible. Research should also be conducted to learn more about using these green building technologies in new hotel construction projects versus retrofitting existing buildings. Many green technologies are easiest to implement in new construction projects, yet existing buildings hold embodied energy that would be lost if the building was torn down. Thus, it would be interesting to explore how green building technologies affect the triple bottom line–economic, social, and environmental factors–when comparing new versus existing build environments.

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Appendix

The Active House Vision and Evaluation Method

The Active House Vision seeks to encourage a holistic approach to building design surrounding three guiding principles–comfort, energy, and environment–to create a built environment that adds to the health and comfort of its occupants without negative impacts on the climate or natural environment[116]. The Active House Evaluation Model assesses buildings on their capacities and efficiencies based on the principles and criteria depicted below in Figure 17. These parameters are user-center and quantified to evaluate real data on the specifications of the building to encourage efficient resource use and minimal negative externalities.[117]

Principles	Criteria Group	Criteria
COMFORT	Daylight	Daylight Factor
		Direct Sunlight Available
	Thermal Environment	Maximum Operative temperature
		Minimum Operative Temperature
	Indoor Air Quality	Standard Fresh Air Supply
ENERGY	Energy demand	Annual Energy Demand
	Energy Supply	Origin of Energy Supply
	Primary Energy Performance	Annual Primary Energy Performance
ENVIRONMENT	Environmental Loads	Building's Primary Energy Consumption during entire Life Cycle
		Global Warming Potential (GWP) during Building's Life Cycle
		Ozone Depletion Potential (ODP) during B.L.C.
		Photochemical Ozone Creation Potential (POCP) during B.L.C.
		Acidification Potential (AP) during B.L.C.
		Eutrophication Potential(EP) during B.L.C.
	Fresh Water Consumption	Minimization of Fresh Water Consumption during Building's Use
	Sustainable Construction	Recyclable Content
		Responsible Sourcing

Figure 17: Active House Evaluation Criteria[118]

[116]Active house.
[117]Active house.
[118]Politi, S. & Antonini, E. (2017, March). An expeditious method for comparing sustainability rating systems for residential buildings. *Energy procedia*. https://doi.org/10.1016/j.egypro.2017.03.006