NET ZERO ENERGY BUILDING ANALYSIS FOR MCDONALDS USA, LLC

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McDonald’s USA LLC has leveraged a team of Masters of Environmental Management students through Duke University to research and propose design aspects and technologies for a retail McDonald’s restaurant to be located in the Chicago area to achieve ‘Net Zero Energy’ classification.

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Executive Summary

As a leader in the global quick service restaurant market, McDonald's USA, LLC ("McDonald's USA") aims to push the limits of its energy efficiency and tasked the Duke team with exploring the possibility of a 'net zero energy' restaurant. This exploration includes researching and proposing design aspects and technologies for a restaurant in the Chicago, IL area to achieve net zero energy (NZE) consumption onsite utilizing the LEED Volume Prototype restaurant as a baseline comparison. This baseline was chosen not only because it is one of the most efficient restaurant designs currently utilized by McDonald's USA, but any restaurant built with the design would also qualify for LEED certification, assuming any recommended changes do not alter the LEED credits in the prototype negatively. The project steps include:

1. Baseline Design and Constraints Analysis
2. Energy efficient technology and design research
3. Run new building design with recommended changes/additions through energy modeling software
4. Design renewable energy systems to meet the resulting decreased energy demand of the proposed 'Net Zero Restaurant' within the designated building constraints
5. Determine any unmet deficit based on project constraints and recommend potential course of actions to meet the deficit

The project focuses on improving current technologies and building design aspects including, but not limited to, the following areas: the building envelope, including roof and wall insulation and window design; the service hot water system (SHW); lighting fixtures and systems; and ventilation system. Due to the heavy influence of McDonald's operational design on its brand, the recommendations included in the analysis account for the restaurant's operational constraints. Some of the more firm operational constraints are kitchen equipment technology and use, the design of the drive-thru area, restaurant hours of operation and peak hours, the supply of refrigeration loading location, and the building code requirements for the desired restaurant location.

To analyze the energy consumption data for the restaurant, the team received assistance from the company's main modeling consultant, Smith Energy Engineering, who utilized the U.S. Department of Energy's eQuest software to run parametric analysis on the original baseline design, each suggested individual technology/design element, and finally a version that combined all technology and design suggestions. The final building model design presents the maximum energy savings possible without violating most of the operational constraints.

The modeled results indicate that McDonald's could obtain a total energy load reduction of 21% from the LEED Volume Prototype restaurant with the technologies and building envelope design changes recommended. The following were largest reductions achieved

- Exterior lighting - 33% individual load reduction
- Heating, cooling and fans - 38% individual load reduction
- SHW load- eliminated since the system's needs are met using heat reclaim systems

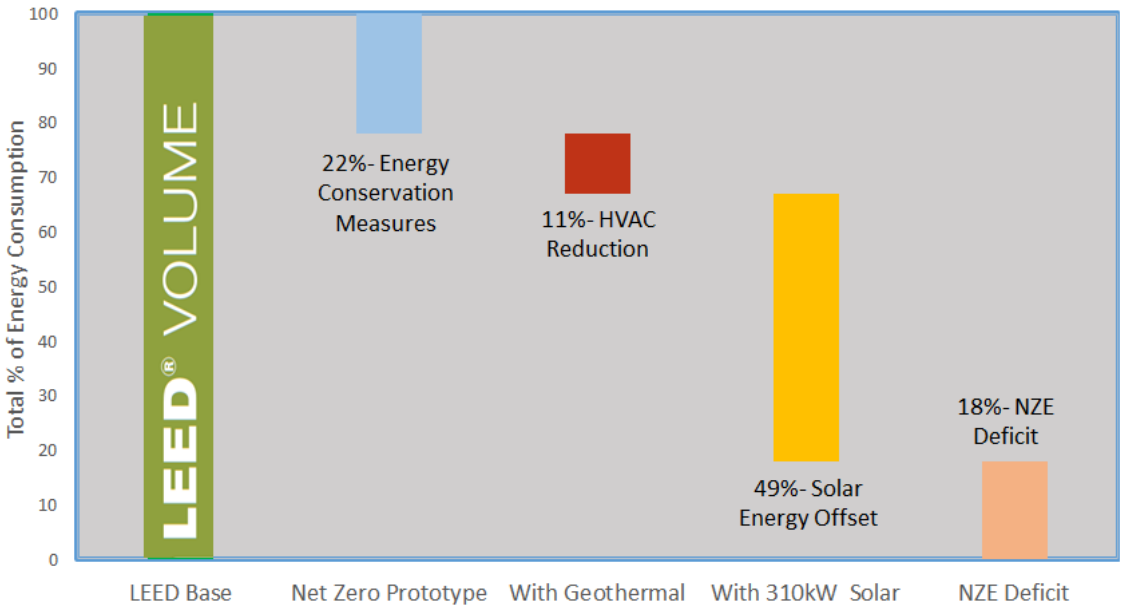
The savings associated with the geothermal system and booster coil (an estimated 1% savings is achieved by using the excess of energy obtained from the condenser unit heat reclaim system) are assumed based on the best information available. The final estimate for the geothermal system assumes a 50% reduction from the LEED Volume Prototype's HVAC load, which equates to roughly an 11% reduction of the total energy consumption of the newly designed restaurant.

Once the total modeled energy consumption of the NZE prototype was calculated, the team determined how much of this energy could be offset with a photovoltaic array of 310kW. The designed system stays within the rooftop and lot space utilization constraints set by McDonald's. The calculations show this system can offset approximately half of the LEED Volume Prototype restaurant energy demand. However, this leaves an energy deficit to achieve net zero energy status (See Figure 11 on p.29).

To meet the energy deficit and to achieve its goal of a net zero energy restaurant, the team recommends examining the following energy reduction options:

- Technologies not currently at market-capacity (such as DC-based LED interior lighting)
- Improving the energy efficiency in the kitchen equipment load by reducing the heat released from certain pieces of less efficient equipment (such as the coffee maker or bun toaster)
- Examining water conservation measures to reduce the amount of energy needed to heat, cool, and move water within the restaurant
- Increasing the amount of onsite renewable energy sources

Finally, the team recommends that the company certify the net zero energy designed building using the U.S. Green Building Council's LEED program and ASHRAE's Building Energy Quotient (bEQ) programs, since McDonald's USA already has experience with the LEED program and the bEQ program has a specific net zero energy designation for fast food restaurants.



*Final Net Zero Ideal Scenario (Sources: data from McDonald's USA, Halton US, *Walgreens US, Alpine Windows, and Alfa Laval and model analysis by Smith Energy Engineering)*

Introduction

Project Outline

The purpose of this project is to research the feasibility of a net zero energy building for McDonald's USA to be built near its corporate headquarters in the Chicago, IL area by specifying which technologies and strategies McDonald's should pursue to achieve net zero energy and analyzing the building model using energy modeling software to determine the feasibility and scalability of the design. As energy consumption makes up a large part of McDonald's operations and maintenance costs for its restaurants, the company has been motivated to reduce its energy consumption through improved technologies and more efficient operations. This project hopes to utilize and build on the company's current progress in energy efficiency by gathering its current data, talking with McDonald's franchisees and representatives and its main suppliers, and exploring what current work has been done in the net zero energy field.

The project analyzes the company's current work in the built environment, its current energy loads within the restaurant, individual technology description, final results and conclusions, and future recommendations and technologies for the company to pursue or investigate that were outside of the project's scope.

Purpose of the Project

With assistance from McDonald's USA, three Duke University Master of Environmental Management students have worked to research and propose design improvements and technologies that would enable a specific McDonald's restaurant design to achieve 'Net Zero Energy' classification. The purpose of this project is for the Duke team to take a 'first look' at the feasibility of a net zero energy building for McDonald's restaurant. While exploring different design elements and technologies, the team will also identify those possibly scalable to other McDonald's based on their usefulness and cost-effectiveness across US climate zones. The research conducted is one of the first known studies to explore the idea of a net zero energy quick service restaurant (QSR). Thus far, net zero energy, focusing on efficiency measures, has not been achieved within the quick service industry in the US. Through technology advances in recent years, a fresh analysis will help shed light on the potential energy reduction in the QSR industry. This project is mutually beneficial, as it allows the graduate student team to work with industry professionals on creating realistic solutions for QSR, while giving the students firsthand experience in private sustainability consulting and providing McDonald's valuable research on how to reduce their energy consumption.

Legal Statement and Master's Project Scope

This Master's Project was written in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment at Duke University. The student team consisted of Emily Conner, Maria Ramirez Millan and Lane Wallace, who are the authors of this report. The student team's advisor was Tim Johnson. McDonald's was pleased to assist the Duke University student team in this work. However, McDonald's is not the author of this report and does not make any claim, express or implied, or endorse any claims made by the authors of this report. In addition to this report prepared for Duke University, a more detailed report will be written and submitted to McDonald's and Tim Johnson for review.

Brief History of McDonald's

The McDonald's brothers opened the first McDonald's in 1948 in San Bernardino, CA. Their idea was simple: a limited menu of quick-service food options at an affordable price. The idea was so appealing that Ray Kroc, then a Multi-Mixer salesman, instantly recognized the potential growth and reached out to

the brothers. In 1954, Kroc officially partnered with the brothers to start expanding the restaurant operations and transformed the restaurant chain into what we know now. For his work with McDonald's, Ray was named one of the most 100 important people of the 20th century by Time magazine.[1] In 1956, the company hired Fred Turner as a grill worker. He would eventually work his way up to become the company's Chairman of the Board. McDonald's began to expand its operations outside of the U.S.in 1967 with its first international restaurant. McDonald's has expanded over the years to more than 34,000 restaurant locations in over 100 countries.[2] McDonald's opened the first Ronald McDonald House in 1974 and established the Ronald McDonald House Charities in 1984.[3] The Ronald McDonald House Charities provide families with children who are in need of hospital care with a place to live at no charge. The company published its first Corporate Social Responsibility report in 2002.

Financial Overview of McDonald's

McDonald's USA is a subsidiary of McDonald's Corporation, which became a publicly traded company in 1965 as part of the New York Stock Exchange. In 2013, McDonald's USA had a net income of $5.58 billion, an increase from what it reported for 2012. The stock has been valued, as of end of 2013, at $97.03, an increase of roughly $35 over the last five years. The company owned restaurant locations were responsible for roughly 51% of McDonald's USA's total revenue (as of 2013). Finally, guest counts in the United States dropped by 1.6% during the company's FY2013.[4]

Sustainability Overview at McDonald's

McDonald's Corporation was recognized as one of the top 100 Best Corporate Citizens by the Corporate Responsibility Magazine in 2010[5]. Recently, the EPA ranked McDonald's USA as one of the top 15 of Fortune 500 corporations in the US for their renewable energy usage.[6] Due to its large environmental footprint, McDonald's Corporation has been focusing on five areas in its effort to implement strategies to minimize the company's impact on the environment and the communities where it operates. These five focus areas are[7]:

- Nutrition & Well-Being
- Sustainable Supply Chain
- Environmental Responsibility
- Employee Experience
- Community

McDonald's Corporation has achieved major accomplishments under each of these initiatives (See Appendix B). Some of the most meaningful examples are in the company's Sustainable Supply Chain program. In January, 2013, McDonald's became the first restaurant chain to serve sustainable fish certified by the Marine Stewardship Council at all of its U.S restaurants.[8] Additionally, McDonald's Corporation joined the Roundtable for Sustainable Palm Oil (RSPO) in 2011 and met the company's goal of requiring all of its suppliers to become RSPO members.[9] McDonald's Corporation is one of the only Quick Service Restaurant (QSR) companies that have joined the RSPO. They are also one of the founders of the Global Roundtable for Sustainable Beef. Most recently, McDonald's Corporation also committed to source "verified sustainable beef" by 2016.[10]

McDonald's began publishing its "Best of Green" annual reports in 2010 to share some of its most successful environmental practices around the world. In the 2012 edition, they highlighted several energy efficiency practices carried out by its U.S Energy Team. These successes include its Energy All Stars program, in which restaurant managers, employees, and/or owners/operators are recognized for management practices that lead to major energy savings in their restaurant's operations. By highlighting these practices in the report, managers throughout the company learn from others' efforts and are

encouraged to implement them in their own restaurants. Other practices highlighted in the report are the *Fire-Up* scheduling tool and the McDonald's USA Restaurant Energy Survey. These tools allow restaurant managers to better control their equipment and to identify the best energy saving opportunities to potentially save between three and six thousand dollars per year.[11]

McDonald's Building Performance

McDonald's Green Building Strategy, part of its Environmental Responsibility program, aims to "gain insight and experience that will help McDonald's USA improve the quality of buildings while reducing the environmental footprint".[12] In 2007, the company became a member of the U.S Green Building Council (USGBC), an organization dedicated to growing the green building industry. By engaging with the USGBC's Leadership in Energy and Environmental Design (LEED) certification program, they have learned more about which building modifications can help them achieve greater energy efficiency (See Appendix D for a more detailed overview of the LEED program). During the last few years LEED Gold certified McDonald's restaurants have been opened in Chicago, Savannah, and Riverside (CA), as well as one in Cary (NC) (The second one in Cary, NC is undergoing the certification process).[13,14] Some of the technologies McDonald's is currently employing in its building design to achieve maximum energy savings include LED lighting, high-efficiency rooftop HVAC units, solar tubes, and skylights with daylight controls.[15]

Recently, McDonald's USA took a step further in its commitment to green building design and became part of the LEED Volume program, creating a building standard from its practice. The LEED Volume program "allows organizations to simplify the LEED documentation for multiple buildings or spaces of a similar type or management, achieving certification faster and at a lower cost than with individual building reviews"[16]. This will allow McDonald's to minimize costs and time during the rating process. McDonald's has stated that "The LEED Volume program builds on the current four LEED-certified restaurants and will continue to progress McDonald's USA's focus on energy, water, waste and material efficiencies".[17] This program also helps McDonald's in the development of the company's "U.S. Restaurant Development (USRD) Environmental Sustainability Plan".[18]

McDonald's has become a leader in kitchen equipment in the QSR industry. Several pieces of equipment utilized by McDonald's is Energy Star certified. McDonald's works collaboratively with its equipment manufacturers to improve efficiencies in their equipment while enhancing their McDonald's operations.

Overview of Net Zero Buildings

Net Zero Energy Buildings come in all different shapes and sizes, from shacks to off grid hotels to traditional style homes, to commercial buildings that involve more complex systems. Walgreens opened a Net Zero Energy Store in Evanston, IL in 2013. This is one of the newest NZEB online and is one the inspirations for this project. It is located just 30 minutes away from McDonald's headquarters and it features 850 solar panels and a geothermal system burrowed 550 feet into the ground[19].

Net zero energy buildings (NZEB) are typically defined as 'net zero site energy', defined as "a site [that] produces at least as much renewable energy as it uses in a year, when accounted for at the site".[20] However, there are several other official net-zero energy building definitions that make a few key distinctions – see Appendix E for full definitions.

Net zero energy is a growing trend that is becoming more attainable financially with the continued advancement and affordability of building technology. According to a recent study by the New Building Institute (NBI), the number of buildings at or reaching for NZEB projects will increase from 99 in 2012 to an anticipated 213 in 2014.[21] While the building industry promotes NZEB as becoming more obtainable and cost-effective with modern technology and building techniques, it is important to identify that building use plays a significant role in in NZEB feasibility. As Figure 1 illustrates, different building use shows a huge range in energy use intensity. A building that stores and prepares food has more difficult hurdles to face to reach NZEB due to the extensive equipment energy use. According to the New Buildings Institute's Research (See Appendix F)[22], most existing and projected NZEB are used for education and office. Although the NZEB market is seeing a significant surge in multifamily buildings, these building types have significantly lower energy use intensity than quick service restaurants and therefore have an easier and more cost-effective path to NZE. Given the specific challenges associated with restaurants, there have not been any traditional full service or quick service restaurants certified as a NZEB in the United States to date.

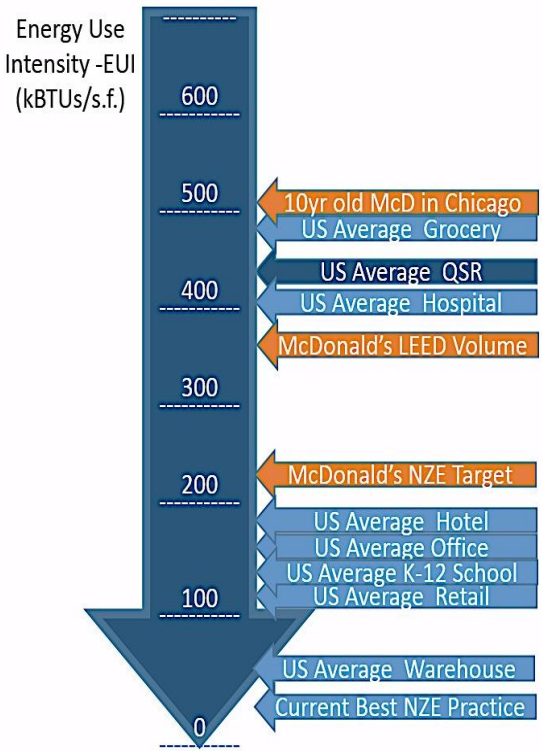


Figure 1: Overview of Energy Use Intensity
(Data sourced from National EUI Data provided and calculated from Energy Star, McDonald's, RMI and Business Energy Advisor. Drawn by Lane Wallace)

Many sources have shown the high potential for energy savings in building performance. However, according to a study performed by NREL that analyzed buildings designed to be net zero energy, NZEB typically fail to meet the levels of savings anticipated in the modeled design. The two primary miscalculations described in the study were that design teams had unattainable expectations of occupant's engagement and consistent behavior in the buildings and modeled forecasts assumed lower energy consumption and higher solar photovoltaic production.[23] NZEB is most successful when designers have an accurate understanding of historical patterns of building use and are able to accurately anticipate expected occupant behavior.

Overview of Third Party Certification

The most prominent and respected certifications for net zero energy buildings are highlighted in the table below. Several third parties offer building certifications that incorporate energy efficiency or Net Zero Energy as a piece of their overall qualifications. These certifications are necessary to create a boundaries and metrics for qualifying NZEB.

It is strongly recommended that McDonald's chose at least one of these certifications, as the third party certification will prevent accusations of green washing. Certification will validate the project in the eyes of the building industry and McDonald's client base. The choice of certification depends on the project objective that McDonald's finds most valuable to the organization: cost savings, visibility of certification

or greatest prestige. McDonald's can also choose to gain more than one certification to validate the project.

Note: The recent Walgreen's project achieved the USGBC's LEED Platinum Certification and is seeking Living Building Challenge Certification.[24]

Table 1: Third Party Certification Overview (For more detailed overview see Appendix D)

Organization & Certification*	NZE Cert.	Overview and Constraints	Notes to McDonald's
US Green Building Council: LEED for 'Building Design and Construction'	No	Currently, LEED does not have a net zero energy credit. However, as part of the Building Design and Construction for New Constructions, LEED offers a credit to encourage energy efficiency, called 'Optimize Energy Performance'. This credit gives points on a scale of energy efficiency compared to similar buildings up to 50% energy savings.	Stay in line with McDonald's LEED Volume certification. Not officially certified NZEB, but easiest in difficulty to achieve.
Green Building Initiative (GBI) Green Globes	Yes	Green Globes is a web-based program for green building guidance and certification and is advertised as a "streamlined and affordable alternative to LEED" [25] As part of the certification, energy makes up roughly one-third of the assessment and includes four evaluation options, including ENERGYSTAR and bEQ program assessments (see below).	Highly focused on energy. Allows for flexible analysis by building types and does not include prerequisite credits.
U.S. Environmental Protection Agency (EPA): ENERGY STAR	No	ENERGYSTAR certifies the top 25% of energy performing buildings within similar facilities types. The program does not include a net zero energy certification or have a specific category for restaurants, only how the building performs relative to similar buildings. [26]	Focuses primarily on building equipment
ASHRAE's Building Energy Quotient (bEQ)	Yes	ASHRAE's Building Energy Savings Program is a building energy rating program aimed at buildings in the design process or those in operation. The system analyzes buildings by type (including 'Fast Food') and gives the buildings a grade on an A+ to F scale. There is a special grade designation for net or 'near net' zero energy buildings.[27]	Focus on energy, and does not address other sustainable building attributes. Recognized primarily only by the building industry, not a well marketed to general public.
Living Building Challenge: Net Zero Energy Building Certification	Yes	In order to get Net Zero Energy certification, the project must also adhere to requirements for LBC's Limits to Growth (in part), Rights to Nature, Beauty + Spirit and Inspiration + Education. The net zero energy component does not allow for combustion on site. It does not grant certification until the net zero energy is proven in performance after year 1 of operations.	Most difficult and prestigious to achieve. Highest accolades.

Baseline Analysis

Base Scenario: LEED Volume Restaurant

McDonald's restaurant designs vary significantly based on a building's age, geographical location, and site orientation, each of which can have a major impact on the final energy demand and consumption. To analyze the technologies that could help McDonald's achieve Net Zero Energy, a "base scenario restaurant" had to be established to analyze the current energy loads and the opportunities for reduction. The LEED Volume restaurant proposal design was chosen as the base scenario, as it is the most efficient and up-to-date building design. Within the LEED Volume category, McDonald's has four individual designs, which vary based on primary construction materials (i.e. masonry and wood) and on total square footage of the building. For this analysis, the LEED Volume 45x97 Masonry & Steel design was selected, since this proposed model achieved the lowest energy consumption compared to the other three designs when selecting Chicago as the restaurant location. Chicago is the desired location for the Net Zero Restaurant given that proximity to McDonald's headquarters is an important factor for the company.

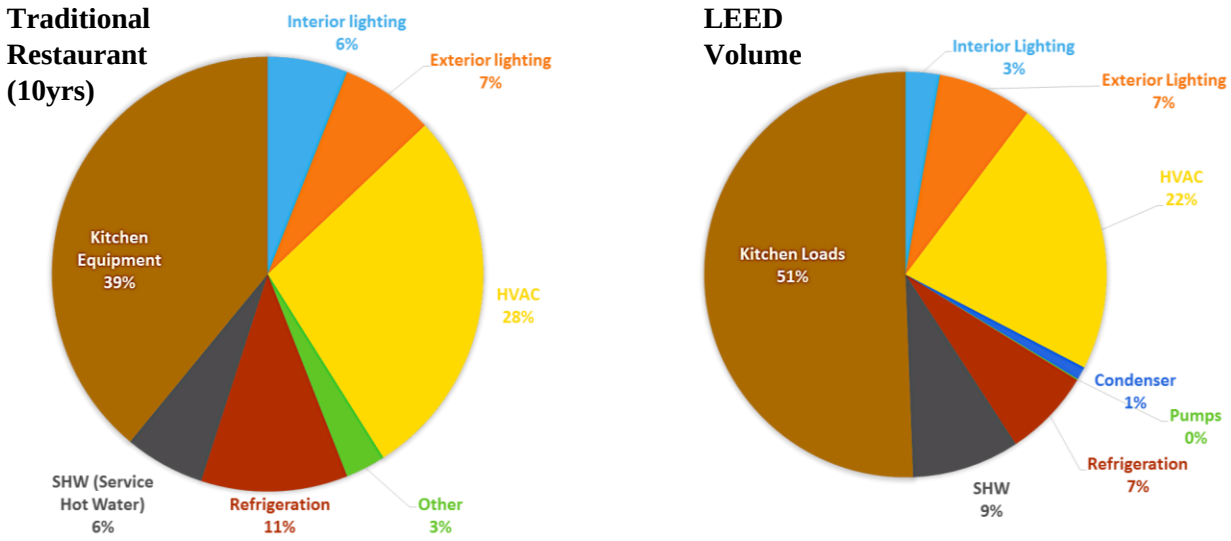


Figure 2: Comparison of energy consumption between a traditional McDonald's and LEED Volume prototype. (Sourced from: McDonald's USA data)

Figure 2 shows the estimated load consumption for this LEED Volume design compared to a standard 10 year-old McDonald's restaurant. The reduction in total energy use by design between the traditional restaurant and the LEED Volume prototype has been modeled at approximately 22%.

Design Steps to Achieving Net Zero Energy

1. Identify hard and soft constraints of building
2. Determine maximum on-site renewable electricity generation potential
3. Determine renewable sources to meet non-electricity energy loads
4. Identify emerging technologies that will improve energy efficiency through changes in building envelope design, lighting, heat recovery, and equipment specifications
5. Create an aggressive-strategy scenario that softens the constraints and makes the NZE goal achievable
6. Generate financial pro-forma and determine recommended course of action[1]

[1] **These steps are based on advice obtained from various industry professionals upon onset of the project. They have been slightly adjusted to meet the demands and constraints of our design.**

To determine the first steps McDonald's could take to build a Net Zero Energy restaurant, this project focused on certain areas of building design that could be improved, and it investigated a series of technologies that could potentially obtain significant energy savings. In terms of building design this project focuses on: changes to the building envelope, including roof and wall insulation and window materials, modification of the service hot water system, and redesign of lighting fixtures. We then looked at new market technologies that could aid in reducing demand kitchen ventilation, HVAC loads and other kitchen heating loads.

Energy Savings Analysis

In order to calculate the energy savings associated with each of the recommendations made, two approaches were taken. First, the building envelope, and lighting design changes together with kitchen equipment efficiencies were modeled on the Quick Energy Simulation Tool (eQUEST) given that these technologies could be modeled on this software. Second, for the rest of the technologies evaluated McDonald's suppliers and the team ran separate simulations to estimate the energy savings. At the end the results of the eQUEST model were combined with those of the simulations to obtain the total energy savings for all the technologies considered.

Review of Energy Consumption and Constraints

Most Net Zero Energy design starts with an analysis of the major energy loads in the building before examining how these can be reduced. The pie charts above illustrate the reduction in loads anticipated with the implementation of LEED Volume design. As observed in Figure 2, the major energy load in the most energy efficient McDonald's restaurant design is the kitchen equipment, which accounts for 51% of the energy use in the restaurant, followed by heating, ventilation, and air conditioning (HVAC) (22%), service hot water (SHW) (9%), exterior lighting (8%), and refrigeration (7%). As illustrated above, the LEED Volume does a good job at reducing all loads except for in the kitchen operations – all other load percentages shrink, increasing the kitchen load's share to 51% of energy consumption.

Within the scope of this project, the team will explore design and equipment improvements that do not impact operations. Due to the heavy influence of McDonald's operational design on its brand, the process design and kitchen equipment loads have acted as a constraint for building modification. For McDonald's to achieve net zero energy, however, it is necessary for kitchen loads to be reduced in some meaningful way. Without a reduction in kitchen energy consumption, net zero energy in a cost-effective way is next to impossible. Beyond the scope of this project, working with equipment suppliers and engineers, McDonald's should look to reduce kitchen loads effectively with minimal impact to the operational efficiency of the kitchen. The SHW systems of the building design could be altered without interfering with the daily operations of the restaurant through heat reclamation technologies, focused on capturing waste heat from the fryer exhaust hoods and from the condenser for the walk-in units. Further, the variable speed ventilation could reduce the fan load without hindering operations. Our project is limited in only exploring these technologies for energy reduction in the kitchen, but it is highly recommended that McDonald's operation and equipment teams explore further possibilities for kitchen load reduction. Due to the high demand of kitchen equipment, extra attention must be focused on the other energy loads in which possible energy savings could be achieved without violating McDonald's operational constraints. Additional constraints such as building layout, drive-thru design, rooftop space, hours of operation, and applicable building codes were also taken in to account.

Constraint Analysis

Summary of Constraints		
Constraint	**Stringency Assessment**	**Nature of Constraint**
Building Size and Layout	Soft	Footprint can be adjusted to add mechanical room.
Kitchen Equipment (Main technology and use phase)	Hard	Process Cooking equipment cannot be managed, this constraint cannot be addressed by our team due to lack of mechanical engineering expertise, but should be actively pursued by McDonald's – recommended equipment updates are highlighted in the future technologies section.
Drive Thru Design	Hard	Despite improved energy-efficiency technologies, McDonald's is not currently considering changing their Drive-Thru design because of business and operational reasons.
Wall Thickness	Medium	The site plan can allow for thicker walls, if necessary, however, this constraint can easily be adhered to using advance insulation technology (closed cell spray foam insulation) that increases R-value per inch. The only threat to this constraint would be with an increase in refrigeration insulation.
No additional rooftop space for equipment	Soft	If mechanical room is added and HVAC/Ventilation load reduced, room will be freed up on the roof. Roof equipment and solar tubes can be added throughout the building as long as the building plan accounts for it in the design phase.
Hours of Operation – heavy energy use required 20hrs daily	Hard	Reducing load by shutting down load hours would hinder operations. For operational and safety reasons, reducing loads in dining areas (occupational sensors) or in parking lots during closed hours is a hard constraint.
Supply and Refrigeration Loading Location	Hard	The floor plan of the restaurant and the loading locations will not help to achieve Net Zero Energy.
Location of the Restaurant	Medium	The team will try to keep to the ideal site plan as much as possible in the design, however adjustments may need to be made (i.e. site size, site orientation). Drive thru design is a fixed constraint.
Building Code Requirements for Location	Hard	Building code for QSR has more constraints than standard building design that have to be accounted for: ▪ Air Flow in kitchen ▪ Lighting (lumens/sqft) ▪ Health and Safety (water temp, lighting, etc.)
Capture Jet	Soft	This technology has an operational constraint in terms of eliminating the space for utensils on top of the grills.

Renewable Electricity Generation

To meet the requirements for NZEB, electricity generation must be included to compensate for onsite energy consumption. This generation can be accomplished through various renewable energy sources such as photovoltaic, wind, combined heat & power, waste to energy and biofuel generation. This project focused on analyzing photovoltaic electricity generation given its cost-effectiveness.

Photovoltaic was the most feasible option for grid-tied renewable energy generation for this project. Solar is relatively cost effective technology with market incentives (See Appendix G for full details on which incentives were included and/or considered) that can be utilized by McDonald's. The maximum size system installed on a McDonald's site is 67 kW in Riverside, CA.

Scenario	Scenario Description
Scenario 1: Mirror Riverside Design Array 1 Size: 21' x 223'	*Mirror to Riverside.* Same array size as Riverside, CA with more efficient modules, to increase system size from 67 to 84.4 kW.
Scenario 2: 2 Ext. Rows Array 1 Size: 21'x 286' Array 3 Size: 21'x 286'	*Two extended arrays on each property edge.* Same design as Riverside, but additional 55' of modules added to array. The two rays are located on the perimeters with one array on the south size of the building and one array on the north side. The array on the north side is flat or angled slightly toward South (feasible racking solutions permitting).
Scenario 3: 2 Rows & BOH Array 1 Size: 21'x 286' Array 2 Size: 21'x 286' Array 3 Size: (4) 21'x 62'	*Two extended rows and 4 small arrays in Back-Of-House (BoH) on lot extension*. Two perimeter arrays on North and South property lines. Four additional solar arrays will be added to small field on the back of the property. Note: Tilt can be increased from 10° so production and space is maximized.
Scenario 4: Array 1 Size: 21'x 286' Array 2 Size: 21'x 99' Array 3 Size: 21'x 286' Array 4 Size: 21'x 99' Array 5 Size: 38'x 36'	*All five proposed arrays.* An additional array can be added as a shelter to the drive thru lane. This would require that the drive through lane have a Southern orientation. Finally, since roof equipment is diminished, an array may be placed over the dining area consuming approximately 40% of the roof space.

Performance and Financial Estimates for Solar Scenarios *(System Design by Lane Wallace)*				
	Mirror Riverside	**Two Ext. Rows**	**Two Rows & BOH**	**Max Solar**
Size (est. kw)	84	216	310	365
Energy Deficit for NZE (est.)	***87%***	***65%***	***51%***	***42%***
Initial investment Estimate[2]	($346,000)	($885,000)	($1,271,000)	($1,500,000)
Potential Incentives[3]	$177,000	$442,000	$635,000	$749,000
Estimated Effective Cost	($169,000)	($443,000)	($636,000)	($750,000)
Estimated Annual revenue[4]	$13,000	$33,000	$48,000	$56,000
Estimated Lifetime revenue	$330,000	$844,000	$1,200,000	$1,400,000

[2] **Initial Investment is estimated using $4.15/Watt installed.**
[3] **Incentives sourced from DSIRE. Includes federal tax credit and bonus depreciation.**
[4] **Calculated using average monthly solar radiation for Chicago as estimated by NREL's PVWatts Calculator <pvwatts.nrel.gov/>**

Considered Technologies Overview

Geothermal

Only a few feet under the ground the soil remains a constant 50°F to 60°F year-round and this is enough geothermal heat to eliminate the need for an outside fuel source to heat and cool buildings. In cooler months, fluid circulates through underground pipes that loop through an electric compressor and heat exchanger that extracts the heat from the pipes and use it to warm the air. This process is reversed in warmer months, using the system to draw heat away from the building and use the ground to absorb it.[28] Commercial buildings with high ventilation demands, still have additional HVAC energy consumption as it will still require the use of fans and motors to properly ventilate the building.

The recommended system design for this project is a central geothermal system that combines a traditional geothermal heat-pump system with the benefits of a centralized air-sourced heating, cooling and ventilation system to provide an even more efficient, reliable and comfortable geothermal system. Although this system still uses a heat pump the coefficient of performance (COP) is higher than a traditional air-sourced heat pump. A four-pipe hydronic system allows designers to significantly reduce the energy use of the systems fans and motors. Benefits of this system include centralized maintenance, lowered noise, enhanced air cleaning and great flexibility in equipment selection and location. This system can help McDonald's clear up space on the roof of the building for other opportunities. A variable-air-volume (VAV) system acclimatizes ventilation air and decreases fan energy. Additionally, this system utilizes air economizers that are able to efficiently handle the kitchen cooling loads on cool days when outdoor air can provide natural cooling.[29]

Finally, the geothermal will provide water-cooled condensers for the major refrigeration loads. This simplified refrigeration system is more reliable with fewer operating parts and provides an opportunity for heat reclamation.

To size the system appropriately, the building load analysis is typically conducted prior to the system design to understand the needs of the building. McDonald's supplier, Trane, is in the process of completing the system analysis and designing it to best match the needs, location, and constraints of the designed building. Trane's previous experience with this type of system allowed them to create a more accurate model that specifically focuses on lower operational and maintenance issues after installation and a higher energy savings impact given the climate zone conditions. For example, in Walgreen's Evanston NZE building, a recently constructed geothermal heat pump system with a CO_2 refrigeration system helped the site achieve about 60% of HVAC energy savings relative to their original HVAC load in the same store in the Chicago area[30].

After reducing heating, cooling and ventilation loads as much as possible, collaboration with Trane is on-going to determine the system design specifications and energy savings. Until the final system is designed, the final scenario utilizes an estimated value of 50% reduction[5] in HVAC loads from the geothermal system.

[5] **This value will be updated upon completion of Trane's analysis.**

Service Hot Water (SHW) Heating System

Currently, McDonald's has standardized the utilization of Bradford White energy efficient tank SHW heating units, either gas or electric versions. The majority of owner-operators choose to install the ultra-high efficient, gas version offered, given the energy savings potential and cost savings of natural gas compared to average electricity rates. For the purposes of our study, the baseline restaurant has installed a gas tank SHW system. The baseline restaurant consumes about 2,000 therms annually.

For this project, we analyzed the utilization potential of heat reclaim units on refrigeration system condenser units on the walk-in refrigerator/freezer and soda machine, as well as a reclaim system on the fryer exhaust hoods in the restaurant. Each of these technologies allows for the water to be pre-heated prior to entering the SHW storage tank, allowing for a decrease in energy consumed heating the water to the required temperature. For each suggested reclaim systems, the water travels through the reclaim system and into a secondary storage tank prior to being transferred to a smaller gas-fired water heater. Each individual setup has been laid out separately below.

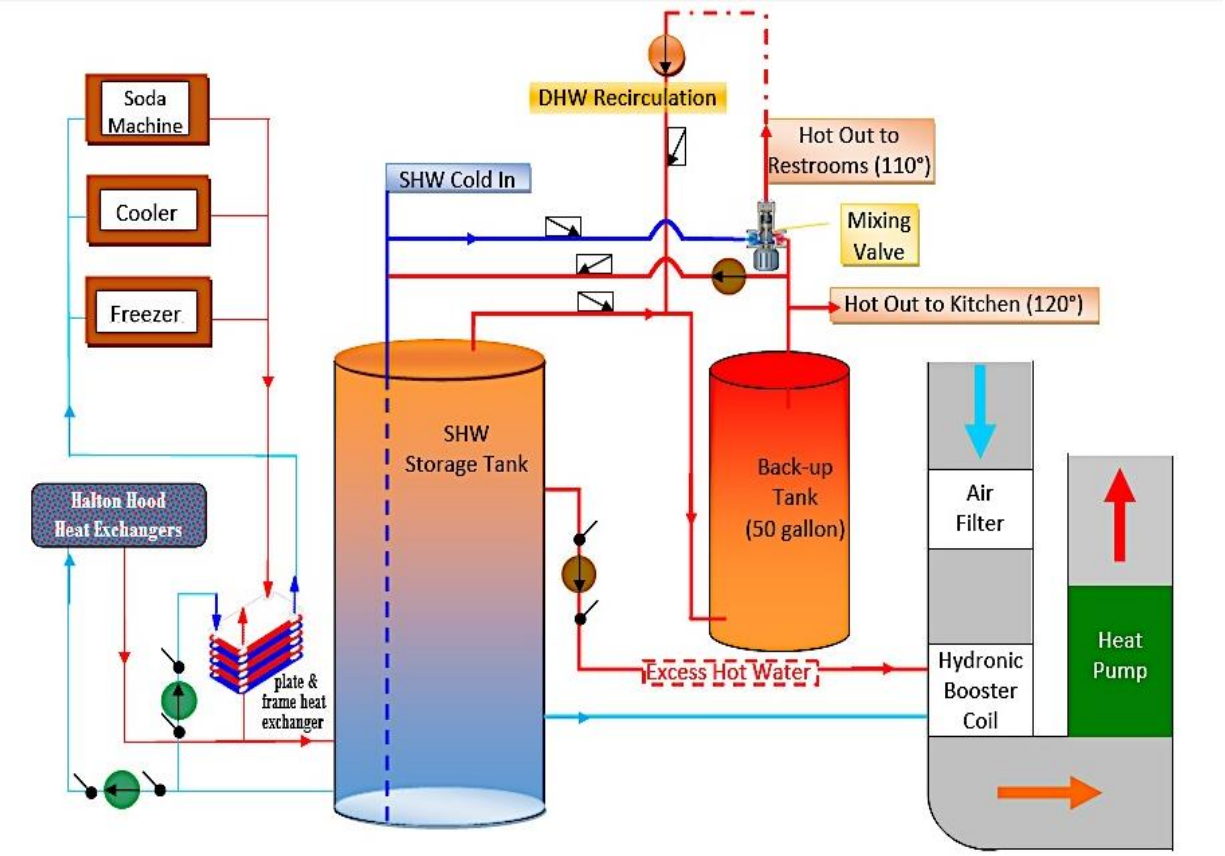


Figure 3: Amended SHW Overview (Drawn by Lane Wallace)

Heat Reclaim Systems for Service Hot Water

The following two technologies were considered to use reclaimed heat to preheat water for restaurant use (SHW). If both technologies are implemented, it is likely that supply of hot water will exceed service hot water demand.

Halton Heat Reclaim Back-shelf Hood

McDonald's gas fryers produce a significant amount of heat while in use. Temperatures in the initial part of the exhaust hood can reach up to about 300-400F degrees. This study aimed to include technologies to capture this heat and use it in other functions within the restaurant to generate energy savings. Halton provides a heat reclaim unit that can be installed in the back-shelf of the hood that "uses a heat exchanger to extract the heat that would normally be exhausted to preheat water supplied to the service water heating system"[31] See Figure 4 to observe the process energy flows. "This cross-flow heat exchanger is installed in the flue-bypass of a Halton KVL back-shelf hood and piped to a storage tank connected to the hot water heat of the site. A circulation pump is installed in-line to transport water through the piping network and all components."[32] A study performed by the Pacific Gas and Electric (PG&E) Technology Center estimated the savings on natural gas consumption by SHW in a QSR restaurant when using the Halton Heat Reclaim device. They quantified the energy recovered from a three-vat fryer and used the test data to calculate the natural gas savings in a hypothetical QSR restaurant. The PG&E study assumed that the water consumption was 500 gallons per day and the fryers cooked 450 lbs of product per day and operated at full load for 3 hours and on idle for 13 hours. The model also assumed the water in the preheated tank would be maintained at 120°F and flow through the heat exchanger at three gallons per minute (gpm). Under these conditions, the study showed the heat reclaim device would save a little over 50% of the natural gas needed to heat the water at this hypothetical QSR (750 out of the 1400 therms). Based on the results of this study, this technology was chosen based on the opportunity to recover some of the heat produced in the kitchen which otherwise would be wasted. It is important to consider that this device may have maintenance costs associated with it, given the grease particles that come with the fryer exhaust.

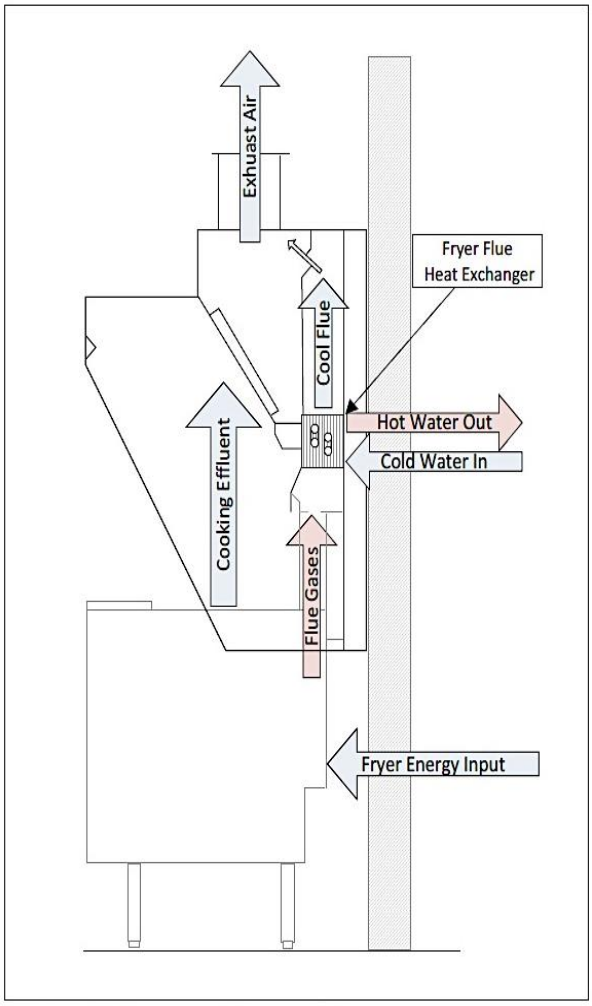


Figure 4: Process Energy Flows of Halton Heat Reclaim unit (Source: Fisher-Nickel, Inc "Food Service Technology Center Summary Report Halton Heat Reclaim Backshelf Hood". 2013.)

For more accurate results of the potential heat reclaim, Halton used McDonald's gas fryers cooking schedules together with the estimated amount of product that is cooked in a typical restaurant and daily water demands to estimate how much energy could be recovered from the flue gases. Their calculations found that the Halton Backshelf hood would be able to reclaim about 400,000 BTU per day, which

translates to around 1,300 therms annually. As previously mentioned, the SHW energy demand in the base scenario is near 2,000 therms per year, so this technology would be able to provide roughly 65% of the energy required by the SHW system.

Refrigerant Heat Recovery System (RHRS)

"Refrigerant Heat Recovery Systems (RHRS) work by harvesting the super heat that would otherwise be rejected by the condenser in a refrigeration cycle." [33] 'Superheat' can be recovered from any piece of equipment with a large condenser unit, such as a walk-in cooler or freezer unit, an ice machine, or an air conditioning system. Any system with a consistent condenser is ideal for heat recovery because it allows for a more constant source of pre-heated water, which is what makes refrigerant systems so attractive to this technology. In a refrigerant cycle, approximately 25% of the rejected heat from the system is considered "superheat" and is "easily recycled into lower temperature water".[34] According to the Food Service Technology Center, "Manufacturers claim that the RHRS prolongs compressor life, enhances condenser performance and reduces refrigeration costs", thus reducing the restaurant's overall costs and energy consumption.[35] The Alfa Laval plate heat recovery system would be connected to the cooler, freezer, and multiplex's water-cooled condenser coils. In this system, non-potable water from the water-cooled condenser units is pumped through the condenser at a low temperature, exiting the system at a high heat temperature. The water then passes through an external plate and frame heat exchanger with potable water running in parallel, transferring the heat from condensing loop to the potable water. This pre-heated potable water is sent to a storage tank at a temperature usable for SHW needs. The reclaim system will capture the excess heat from the water cooled units in the cooler months and when no heating is necessary the compressor systems will be used to cool the systems. The non-potable water additionally passes through a geothermal system to bring the water back to a cooler base temperature for more energy efficient management.

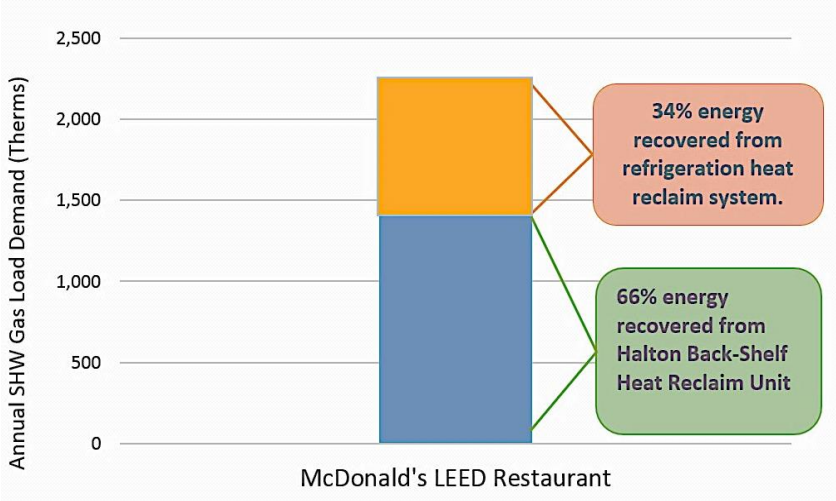


Figure 5: Offset Annual Therms from Service Hot Water by Heat Recovery Technology

The calculations for the total available therms reduced by including a plate heat exchanger to recover the waste heat from the condenser units was done based on the potential heat reclaim off the water-cooled units, the amount of condenser run time during the day, and the kW capacity of the units. This was used to calculate the total heat rejection of the three units, which was summed and adjusted by 10% for uncertainty to one final total recoverable Btu value. Using a rough estimate of this final value[6], as they are not a direct McDonald's supplier, a local supplier of Alfa Laval products was able to send us an estimated system that could convert this total recoverable heat into values, including a total gallons per minute output at the desired temperature and the kBtus per hour of the rejected heat it utilized, to be used in conjunction with

[6] **No exact information or any reference to McDonald's or this project was made during this process.**

Halton's final calculations for their hood system to produce a total annual therms saved and gallons per day of SHW produced.

As observed in Figure 5 this system allows for the reclamation of an additional 34% of the energy necessary to completely meet the demand of the SHW system, leaving around 1,200 therms of excess energy that could possibly be used to reduce HVAC load further.

Excess SHW for Duct Booster Coil

Using a hot water duct booster coil, additional SHW at varying temperatures can be used to preheat the air circulating through the duct system, thereby reducing the load on the heat pump. An example of a booster coil can be seen in Figure 6.[36] Using back-of-the-envelope calculations, based on the gallons per minute (GPM) and estimated output temperatures from the heat reclaim systems approximately the equivalent of nearly 300 therms can be saved using this technology. However, the geothermal system and booster coil specifications will largely factor into realized savings. Collaboration with Trane to more accurately measure these savings are still underway.

Figure 6: Illustration of Booster Coil | *(Image Source: MultiTherm "Chilled Water Coils" N.d. http://www.multithermcoils.com/chilled-water-coils.html)*

Additional Plumbing Efficiencies

Due to the variability of water temperature from reclaim technologies, it would be beneficial to add two mixing valves to ensure water is provided at a safe temperature. A mixing valve to temper output temperatures for domestic use to 105°F would ensure safe temperatures to clients while significantly reducing hot water demand throughout the day. A second mixing valve for commercial kitchen use will maintain a constant output at 125°F to ensure code is met, but not exceeded for safety and efficiency purposes.

The service hot water may include technology that will recirculate water to the restroom sinks to provide instant hot water, reducing water use and system efficiency. During high demand time frames the system will automatically kick-off. If a recirculation system is considered in conjunction with mixing valve technology, the return should be connected to the storage tank, instead of the primary tank, as the return water will be less than 105°F and temperatures will need to be re-heated before re-use.

Heating, Ventilation, and Air Cooling Load

Variable exhaust management system (VARI-VENT)

The cooking equipment (i.e. fryers and grills) at McDonald's is equipped with multiple exhaust systems to take out the hot air produced from the cooking processes. Traditionally, these exhaust fans operate at constant high speeds, even when the cooking equipment is idle. VARI-VENT technology communicates with the cooking equipment to control the fan speeds according to

Energy Load	VARI-VENT estimated savings
Heat (Therms)	7.16%
Cool (kWh)	1.41%
Exhaust (kWh)	3.42%

Table 2: VARI-VENT estimated saving (Courtesy of Halton US)

the cooking loads. It has the ability to automatically increase or decrease the fan speeds to eliminate unnecessary exhaust run time. This can create two significant energy savings: (1) the motors for the exhaust fan would run less and (2) less replacement (make-up) air would need to be heated or cooled by the HVAC system. As estimated by Franke®, VARI-VENT could reduce exhaust fan energy consumption by a conservative 35% and potentially up to 50%, and HVAC load by approximately 5%.

McDonald's is currently testing VARI-VENT technology in several of their locations and has obtained promising results. Reducing the ventilation load would have a significant impact in driving overall energy consumption at the restaurant, since it would also affect the amount of air heated or cooled by the HVAC system.

The Halton Company simulated the possible energy savings that would be obtained with VARI-VENT according to the cooking schedules of the fryers. They assumed an 18 hour fan schedule and they adjusted the fan speeds ranging from approximately 70 to 100% according to the cooking load. Figure 7 shows the fryers cooking profile that was used in the calculations on an hourly basis for both week and weekend days.

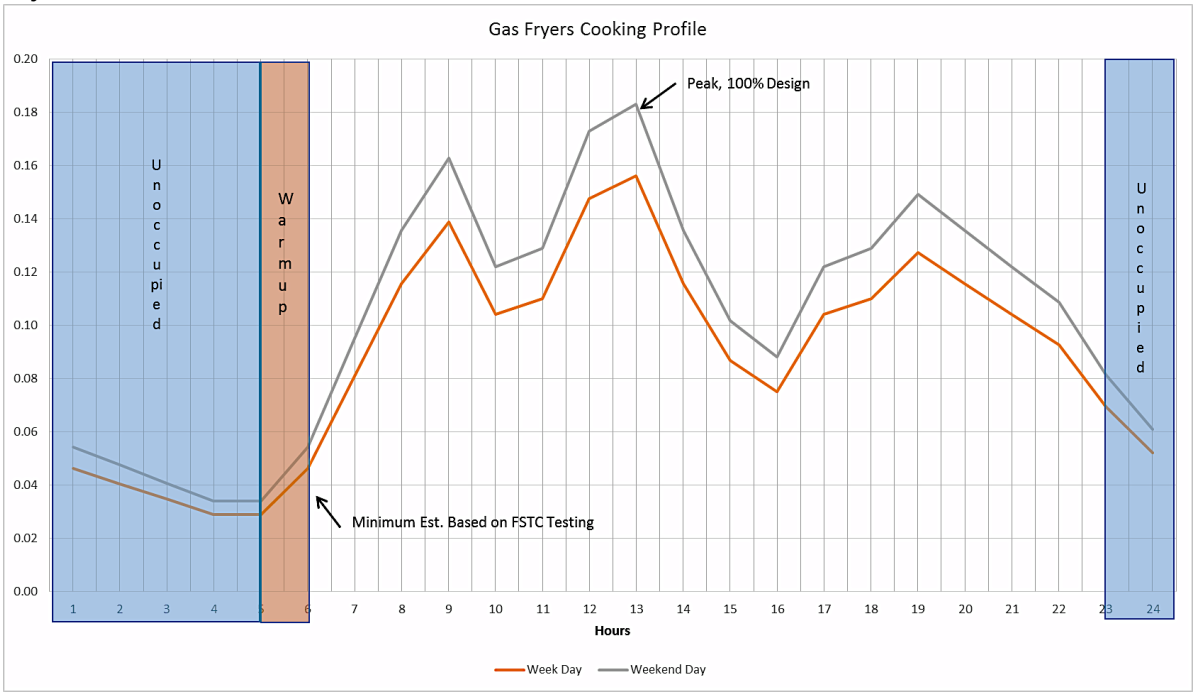


Figure 7: Daily Gas Fryers cooking profile (Source: figure courtesy of analysis by Halton US)

Using this cooking profile, the speeds were adjusted for the three exhaust fans (2 over the fryers, 1 over the grill) and the energy savings on exhaust energy consumption (kWh), heating (therms) and cooling (kWh) loads were calculated. As observed in Table 2, VARI-VENT helps to reduce the energy consumption of the exhaust fans by 3.42%, it reduces the therms used in heating by 7.16% and the energy used in cooling by 1.41%.

Capture Jet®-Halton KVL Hood

To calculate the energy savings associated with installing a Halton KVL Hood with the Capture Jet® technology, a parametric run was carried out on eQUEST in which the ventilation on each hood was dropped by the percent of savings obtained by having lower exhaust volumes, measured in cubic feet per minute (CFM), in each hood.

Energy Load	% of savings
Heating (Therms)	36%
Cooling (kWh)	-4.6%
Pumps (kWh)	5.0%
Fans (kWh)	2.2%

Table 3: Energy Savings obtained with Capture Jet (Source: data courtesy of McDonald's USA)

As ventilation is a major energy load at a McDonald's restaurant and has a significant effect on the heating and cooling loads of the building, multiple approaches to reduce the associated energy consumption were evaluated. The Capture Jet® technology offered by Halton Company "creates air curtains to assist in capture and containment of heat and effluents in the critical work area".[37] This technology "reduces the effective net exhaust volumes while improving extraction efficiency, with fan and ductwork size minimized"[38]. The air curtains created by Capture Jet drive the thermal plumes directly into the extractors and increase hood velocities. Compared to traditional exhaust hoods (suction only), Capture Jet requires 20 to 40% less exhaust volume for extracting a comparable heat and contaminant load. Additionally, the hood is equipped with KSA cyclonic filters that removes 95% of grease particles, generating monetary savings not only in the exhaust fan energy use but also in maintenance costs. According to Halton, Capture Jet® can reduce an overall kitchen energy bill by 30%. Even though there are some operational constraints associated with the installation of Capture Jet technology, such as the availability of space to place grill utensils, the team decided to incorporate it in the analysis because of its great potential to reduce the ventilation load and to downsize the Roof Top Units (RTU), given the reductions obtained in the HVAC loads, which after cooking equipment are the largest energy load in the restaurant.

This individual eQUEST parametric run shows the individual energy savings of installing Capture Jet®. As observed in Table 3, the main impact of this technology is on reducing the heating load of the restaurant, which decreases by 36%. Additional savings are seen with the pumps (5% savings) and the fans (2.2% savings). Conversely, the cooling load actually increases by 4.6%, but the amount of energy already saved on heating largely offsets this increase. The final savings from Capture Jet are from the downsizing of the HVAC system due to this decrease in heating demand. Further simulations on eQUEST would need to be completed to estimate these savings by downsizing the Roof Top Units in the model.

This technology has an operational constraint with the current kitchen operations standards in McDonald's.

Building Envelope

Roof

The base LEED Volume McDonald's restaurant prototype has an insulation with an R-value of 25, which is higher than the average Quick Service Restaurant (QSR) R-value of 15. The U.S. Department of Energy (DOE) in their *Technical Support Document: 50% Energy Savings for Quick-Service Restaurants* recommends an ideal roof insulation value of R-30 for a QSR located in climate zone 5 [39]. For this reason, several parametric runs increasing the insulation R-value for the roofs to a value of 5, 45, 60 and 100 respectively were modeled in eQUEST to observe which value had the highest potential energy savings. According to this analysis, we chose an R-value of 100.

Walls

Currently, McDonald's LEED Volume restaurant structural walls are built with Concrete Masonry Units and a metal stud with R-19 insulation. Depending on the type of assembly, McDonald's walls' R-value can be either R-18.5 or R-20.4. In wall insulation as well, McDonald's is ahead of most QSRs, with the average R-value of R-13 reported by the DOE. The DOE recommends QSRs in climate zone 5 set the thermal performance of exterior above grade/wood frame walls to R-23[40]. Using the same approach described above, several parametric runs were simulated on eQUEST to find the optimum R-Value for the walls. The values tested were 5, 25, 40, 60 and 100. The 'per inch' value of the insulation decreases exponentially due to lower increased performance and higher costs associated with the insulation itself. Additionally, the cost to increase wall thickness can be significant. Hence, we chose R-60 as opposed to R-100 as a final R-value, aiming for a more cost-effective solution. In our final model, we determine a higher value of additional insulation in the Front-of-House versus Back-of-House (BoH). In the BoH, when more insulation is added it actually increases the cooling load as it is more effective at trapping in radiant heat from the kitchen equipment. Our final model therefore only uses R-40 in the BoH walls. On the outset of this project, we recommend McDonald's works with insulation experts to determine the highest R-value that is economically feasible.

Windows

There are four aspects of windows that must be decided upon when discussing energy efficiency: the frame, glazing, number of panes, and filling air between panes. Each of these aspects of window design will impact the efficiency of the window and the effect on ventilation requirements for ventilation. For this analysis, the scenario utilized two types of windows from the Alpen 925 series- 9L and 7L. These two windows are a high performance window with quadruple-pane glazing and foam-filled fiberglass frames to allow for a higher R-value, and thus higher efficiency. The 925 9L series is filled with inert gas, utilizes low-e glazing, twin suspended films, and warm-edge spacers. The 9H series is similar to the 9L option except that it is filled with krypton gas, which allows for a higher visual transmittance but lowers the R-value slightly. Both of the gases used in the windows allow for a higher insulation value compared to traditional air. [41] The model chosen for the Net Zero prototype was the 9L-9H given that it obtained higher energy savings on the parametric run performed with eQUEST.

The energy savings for the combined insulation (both walls and roof) and the window changes were also modeled in eQUEST. The energy savings associated with these changes are mostly observed in the heating loads. The percent savings obtained with each building envelope modification can be observed in Table 5.

	U-Factor	R-Value	Solar Heat Gain Coefficient	Visual Transmittance	Condensation Resistance Factor (CRF)
925 9L[42]	0.11	9.1	0.25	0.39	73
925 9H	0.12	8.3	0.37	0.49	72

Table 5: Window Design Inputs (Source: Alpen High Performance Products (HPP))

Energy Load	R-100 on Roof estimated savings	R-60 on Wall estimated savings	Alpen HPP windows
Heat (Therms)	4.1%	4.0%	4.7%
Cool (kWh)	-0.4%	-0.6%	-0.5%

Table 4: Energy savings results from added insulation and high efficiency windows (Data source: McDonald's US and Alpen HPP)

Lighting

Kitchen Lighting

Currently, McDonald's USA uses T-8 CFL fixtures in the back of house area, which includes the kitchen. To update this area to be consistent with the rest of the restaurant spaces, these will be replaced with LED fixtures according to the new Walnut St., Cary, NC location, which is in the process of obtaining a LEED certification. eQUEST models predict an additional savings of 17.5% in the overall interior lighting system.

Daylight sensors have the potential to save an additional 22.5% of interior lighting. By strategically placing daylight sensors near solar tubes and windows, the EMS system will dim or turn off lighting when sunlight is sufficient. Due to the significant reductions in energy use by using LED lights, the daylight sensors have a low return on investment at this time, hence they are only recommended for the net zero project in order to maximize energy reduction.

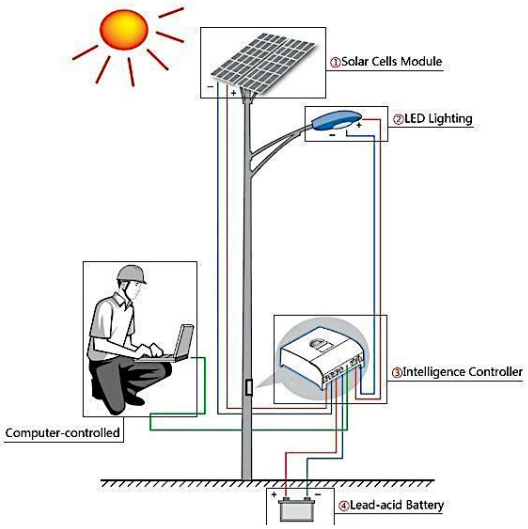


Figure 8: Single Unit Pole Mount Solar Lighting (Image Source: Alibaba. "100W IP66 solar LED street lamp for outdoor energy saving solution" Alibaba: Street Lights. *N.d. http://www.alibaba.com/product-detail/100W-IP66-solar-LED-street-lamp_814873967.html*

Exterior Lighting System

Exterior solar LED fixtures would be beneficial investment for McDonald's. These fixtures use direct current (DC) creating an off-grid system that is more efficient than a line voltage AC solution. The solar production instead of being converted from DC to AC, directly supplies the lighting system, eliminating the 5% to 10% inverter loss. Additionally, the low voltage current system and the elimination of circuitry that downgrades the current can result in 10% additional energy savings. A combination of LED floodlights, under array canopy, and pole-mounted lights should be installed for adequate lighting. The pole lighting can operate as independent units where feasible – see Figure 8. Where single unit systems are not possible, a small portion of the array (to be sized by solar and lighting designers) should be directed to supply power to DC fixtures (see Figure 9). Battery capacity is typically designed to account for 3 continuous cloudy or rainy days backup.[43] Battery storage can be customized based on McDonald's specifications to secure safety and security in exterior lighting.

The standard design components are:

- Solar Panels – 25 years
- LED light – 50,0000 hours
- Controller – 10 years
- Battery – 5-6 years [44]

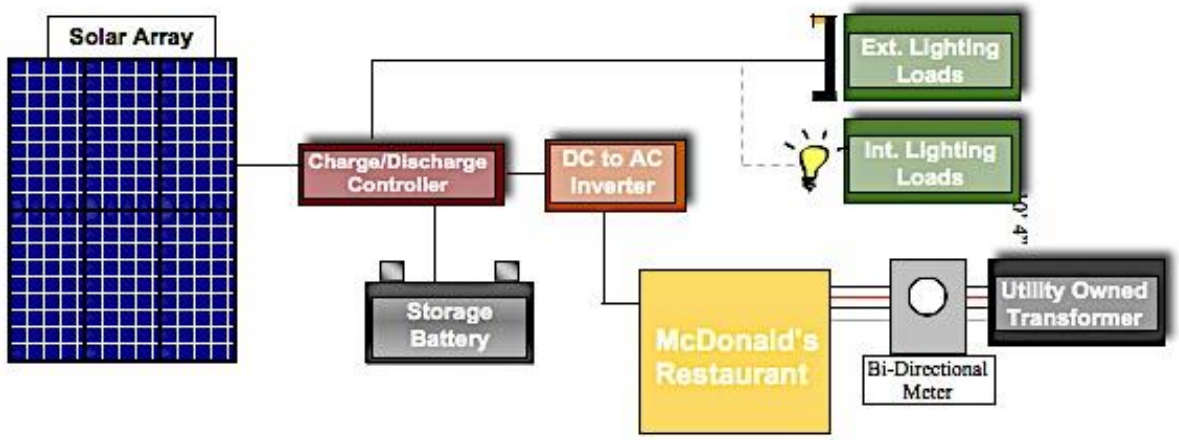


Figure 9: Schematic of sample DC-based lighting system using solar PV (Source: drawn by Lane Wallace)

Because of the economy and practicality of this technology, there are a variety of vendor options possible for lighting fixtures – some freestanding with solar component and some ready to be wired to existing solar component. McDonald's can work with existing and trusted vendors to determine the best fixtures and brands for this project.

Third Party Energy Management System (EMS)

The LEED Volume Design calls for an EMS, however currently these systems are often installed and quickly forgotten about by many companies. NREL recently did a study showing that one of the big contributing factors of net zero energy buildings not actually operating at net zero energy is the on-going mismanagement of these systems. This study was done on large buildings (like apartment complexes, schools, or office buildings) which always have at least one person whose responsibility is solely building management. Because of the small square footage of a McDonald's restaurant the general manager is burdened with this responsibility and has much higher priorities than energy load management. Instead of training hundreds of general managers in building efficiency and complex software systems, it could be cheaper and more efficient for McDonald's to have one party responsibly for all of its energy management.

Through third party management McDonald's could expect the following results:

- Customized efficiency of building systems that account individual restaurant and site factors
- Real-time system adjustments for improved efficiency
- Reduced training time for GMs
- Additional working hours for GMs
- Reductions in system tampering/overrides that reduce efficiency
- Closer management which will reduce accidental energy losses
- A working relationship with a management company and other restaurants for on-going improvements

McDonald's current standard is to install an EMS at every new or rebuilt restaurant. Their approved suppliers are Franke and Siemens; hence, we would recommend utilizing one of the two approved systems or an upgraded system as deemed necessary by the scope of the project.

Summary of Results and Recommendations

According to the individual technology parametric eQUEST results, an ideal scenario was designed with the aim of maximizing the possible energy reductions, even if some the technologies fell outside of McDonald's operational constraints. The scenario utilizes R-values of 100 for the roofs, R-60/R-40 for the walls, 7L-7H Alpen super windows with fiberglass frames, full LED lighting fixtures, Solar DC powered lights for the façade and light poles of the exterior, and a Halton KVL Hood with Capture Jet® technology.

Other technologies were added to the net zero ideal scenario, including a geothermal heating and cooling system, VARI-VENT, and heat reclaim systems for the exhaust hood fryers and the condenser unit. A full list of each of each of the components of the net zero ideal scenario can be found in Appendix C.

We used a two-step strategy to calculate the total energy savings that could be obtained with the Net Zero Ideal Scenario: calculate total energy reduction and then meet the remaining consumption with onsite renewable energy. First, an eQUEST model was created to evaluate the final energy consumption of the restaurant by integrating all the previous individual parametric runs for the building envelope changes (insulation and windows), the new lighting design features and the implementation of Capture Jet®. This integrated model assesses the interaction of all the changes in the building, and produces a more accurate number for the total energy consumption of the Net Zero prototype restaurant. To account for the savings obtained with VARI-VENT (which was not included in the eQUEST model), the team used the saved kWh (in exhaust and cooling) and therms (heating) obtained in the Halton simulation, and subtracted these from the final energy loads results generated by eQUEST.

Figure 10 illustrates the difference between the final energy profile of the Net Zero Energy (NZE) Prototype and the LEED volume base scenario. The total energy reduction from the base line to the NZE prototype is 21% (these are the aggregated savings for all the loads). As it can be observed in the figure, exterior lighting still represents about 7% of the total energy consumption; however, this load by itself was reduced by 33%. Further energy savings were achieved in the heating, cooling and fans loads, which together went down by 38%. Additionally, due to the energy recovered on the heating reclaim systems, the SHW load is completely removed and a surplus of 1% in saving is achieved by using the excess of energy obtained from the condenser unit heat reclaim system.

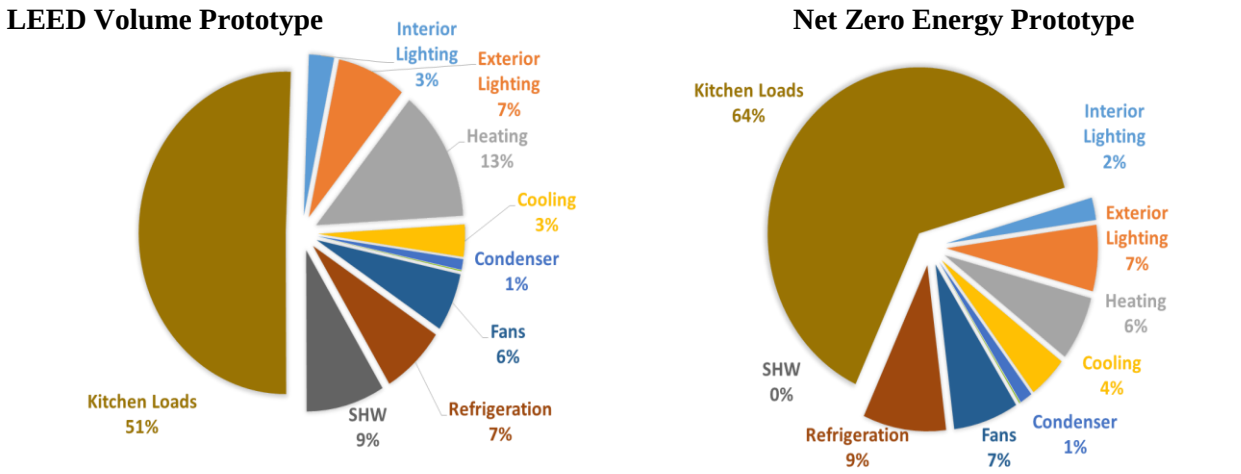


Figure 10: Comparison of energy consumption between LEED Volume base scenario and Net Zero Energy prototype (See Appendix H for larger view) (Source: data from McDonald's USA, model analysis by Smith Energy Engineering.)

The second step taken was to integrate the energy savings that could be obtained with the geothermal system. Ideally, Trane would design a system according to the heating and cooling loads of the NZE prototype. For the purposes of this report, however, the savings associated with the geothermal system and booster coil are assumed based on the best information available. The final estimate assumes a 50% reduction from the original HVAC load, which is about an 11% reduction of the total energy consumption of the restaurant. McDonald's should verify these numbers with Trane once the geothermal system design is complete.

Once the total energy consumption of the NZE prototype was obtained, the team calculated how much of these energy could be offset with a Photovoltaic array of 310kW (Solar Scenario 3). Estimating that this system could offset approximately 50% of the LEED Volume restaurant energy demand, the project was left with a deficit of 18% to achieve Net Zero Energy in the McDonald's restaurant proposed. The reduction steps from the LEED base volume to the NZE deficit of 18% can be observed in Figure 11.

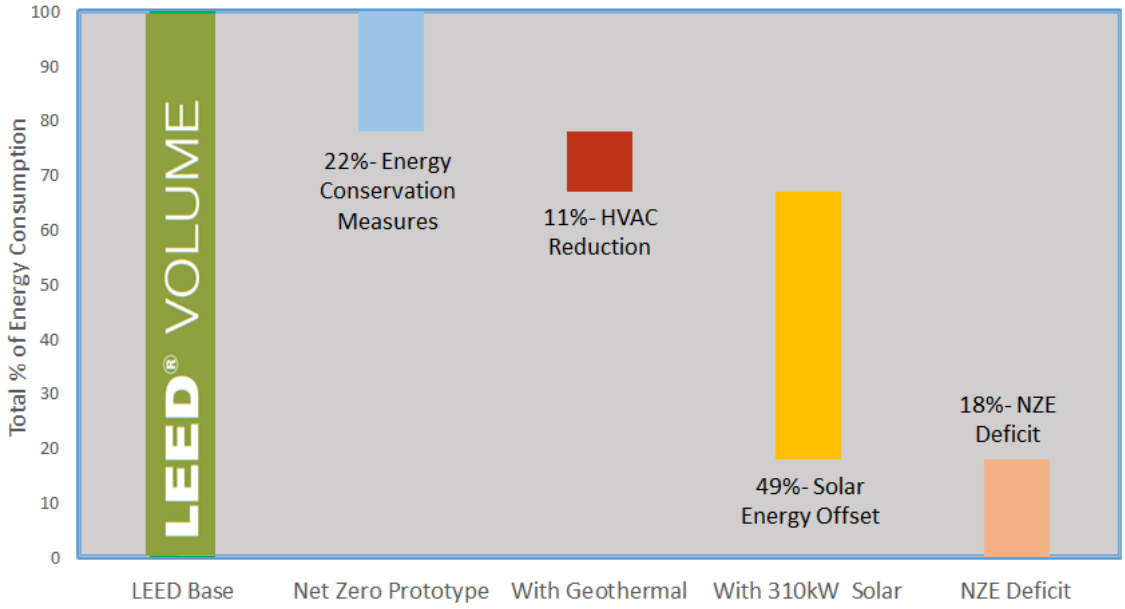


*Figure 11: Final Net Zero Ideal Scenario (Sources: data from McDonald's USA, Halton US, *Walgreens US, Alpine Windows, and Alfa Laval and model analysis by Smith Energy Engineering)*

Future Recommendations

Applicability of Analysis

This analysis is applicable to areas in the United States with similar climate and temperature zones as the Chicago area- i.e. climate zone 5 and cold temperature,[45] due to the variability of HVAC loads based on these two factors.

The renewable technologies in the analysis might vary based on solar irradiance, high speed winds availability, and incentives availability.

Future Technologies

Solar Thermal Water Heating

Solar thermal water heating is a technology that could be used and is cost-effective for a NZEB, however McDonald's unique energy loads make the reclamation systems preferable. The reclaimed heating systems has a higher returns, requires less equipment investment, while simultaneously reducing cooling load requirements. Further, the on-going electricity use for pumps is greater than the reclaimed system due to the constant recirculation vertically to the roof. Solar thermal could be used as an alternative if reclaimed technologies are not feasible or do not provide enough hot water to eliminate the service hot water demand. If this option is explored further, the SHW designer should consider using DC voltage pumps powered by the SHW system. This has the advantage of lower energy use and higher efficiency, and will allow the system to be fully functional in the case of a grid power outage.

DC Power-Based Interior Lighting Systems

DC based lighting systems have been popular for recreational use in RVs and recreational boats for decades. In recent years, as solar has grown in popularity, DC lighting systems and related bulbs are becoming more available. Homes, offices and retail installations are to market with this technology at

cost-effective rates. In comparison with traditional LED systems, a DC based system has lower upfront installation costs and annually energy and maintenance expenses. As the wiring is low voltage, no electrician is needed to install or maintain the system and it can also readily transmit data for easy management. The system can run on battery power for days in case of an emergency.

In our research, we were unable to find DC lights with a high enough lumen output to meet standards for a commercial kitchen, although we recommend reaching out to lighting experts for confirmation. This technology would be a sound consideration for Front-of-House use in the NZE project. We were unable to get accurate cost and energy saving information without using outside vendors who were not under NDA. Therefore, we were unable to re-design the lighting system using DC in the scope of our research.

CO_2 Based Trans-critical Chiller System

To further reduce the HVAC and refrigerant loads on the restaurant, a CO_2 trans-critical chiller system (similar to the one located at the Net Zero Energy Walgreens location) could be installed. The main advantages of such a system include an increase in energy savings from multiple restaurant loads, elimination of HFC-based refrigerants, and potential coordination with a heat recovery system, such as a heat pump cascade or a de-superheating system. A recent study has shown that the performance of CO_2 systems can match or exceed the performance of conventional refrigerants in many applications.[46] When used in conjunction with a heat recovery system, the restaurant can continue to meet its SHW needs and reduce the condenser pressure, enabling further energy savings.[47] Finally, these systems are optimal for locations that require simultaneous heating and cooling needs[48], meaning in the cold Chicago winters these systems would be ideal for running both space heating and refrigeration needs.

	Control restaurant in Esbjerg				HFC-Free restaurant in Vejle			
	Refrigerant	Charge Warming Potential (gr)	Global ($KgCO_2/Kg$)	CO_2 (Kg/CO_2)	Refrigerant	Charge Warming Potential	Global	CO_2
Post-mix	R404A	1616	3200	10601	Propane	646	3	4.0
Juice	R134a	155	1300	413	Propane	70	3	0.4
Shake	R404A	2835	3200	18598	Propane	1419	3	8.7
Meat freezer	R404A	270	3200	1771	Propane	100	3	0.6
Wall freezer	R404A	270	3200	1771	Propane	100	3	0.6
Ice cube	R404A	1200	3200	7872	Propane	450	3	2.8
Salad cooler	R134a	100	1300	267	Isobutane	40	2	0.2
Walk-in	R134a	10000	1300	26650	Propane	1000	3	6.2
HVAC	R407C	17000	3000	104550	CO_2	12000	1	24.6
Direct emissions (kg CO_2 in lifetime)				172493 12%				58 0%
Indirect emissions (kg CO_2 in lifetime)	Energy consumption (kWh) Per week / In lifetime 2383 / 1858740 / 1208181				Energy consumption (kWh) Per week / In lifetime 2202 / 1717560 / 1116414			
Total emissions				1380674				1116472
Reduction in Vejle								19%

Figure 12: HFC-Free Pilot Restaurant Results (Source: Austin, Brian T., K. Sumathy, "Transcritical carbon dioxide heat pump systems: A review", Renewable and Sustainable Energy Reviews, Volume 15, Issue 8, October 2011, Pages 4013-4029, http://dx.doi.org/10.1016/j.rser.2011.07.021.)

In 2004, a McDonald's location in Denmark participated in a pilot project with UNEP to install a CO_2 refrigeration and HVAC system (along with other non-HFC based products) to allow their building to be considered HFC/CFC-free. This project came about after a 2000 meeting at the McDonald's U.S. Headquarters building with UNEP, supplier, industry, and EPA representatives to discuss alternative refrigerants to HFC-based systems.

Full results from the project can be viewed in Figure 12. The results of the project focused on safety, energy consumption, and costs compared to current commercially viable technologies. The entire system's results show a reduction the overall energy consumption by 12% and emissions over its lifetime of 27% (as seen in Figure 12).[49]

The technologies used in this project that could be applied to the Net Zero restaurant include: the TC180 ice machine by Scotsman that uses propane as a refrigerant and meets necessary safety standards; ice cream maker and shake machine by Taylor/Carrier using propane as a refrigerant; the multi-mixer drink system by IMI Cornelius (located in the U.S.) using propane as a refrigerant; and a compressor by Danfoss using CO_2 as its refrigerant. The study suggests that these technologies would need roughly 2-4 years for R&D, which suggests that these technologies are currently ready for deployment at restaurants.

Pavegen Tiles

Pavegen floor tiles generate renewable electricity via kinetic energy as they are stepped on. These tiles made their global debut at the 2012 London Olympics, where 20 tiles were installed along the central crossing of the Olympic stadium to power roughly half of the nearby mall's outdoor lighting. The tiles are waterproof and made from 100% recycled rubber for the surface and 80% recycled material for the slab.[50]

The electricity produced by these tiles can be used to either supply low-powered, nearby technologies (i.e. outdoor LED lighting or signage) or it can be stored in a battery system to be used at a later time. Each footstep produces enough electricity to power an outdoor LED light for roughly 30 seconds.[51] By powering a portion of the exterior lighting with these tiles, less of the solar PV array will need to be diverted to this load and can be focused on the interior (i.e. kitchen) load.

The additional benefit of these tiles is the publicity associated with using them. Along with the system, Pavegen software shows the real-time energy generation that can be displayed via their app on a separate LED display (that can be powered by the tiles itself) or a mobile device. The tiles would also be a novelty that can bring customers into the store, rather than going through the drive thru, which would allow customers to come in and see the energy efficient technologies inside the store, as well.

Topics for Future Research

Waste

This report does not include an analysis of wastes at McDonald's restaurants. However, the company is focusing on reducing wastes and waste diversion from landfill. For solid waste, McDonald's takes a "total life cycle" approach, focusing on reducing packaging and materials of products and diverting as much waste from the solid stream system as possible. McDonald's works on these goals through the practices of reduction, reuse, recycling, and composting as much material as possible. For example, the average McDonald's U.S. owned and operated restaurant recycles more than 17 tons of corrugated cardboard material and approximately 13,000 pounds of cooking oil per year.[52] While currently, some of restaurants have switched to a bulk oil delivery system over the current plastic and corrugate jugs, this is one main area of potential waste reduction that has not been fully realized by U.S. restaurants.

Future analysis on the waste consumption by an average McDonald's should include a waste audit of solid wastes sent to landfill, recycling, and compost (when applicable) to better understand the waste streams. This analysis should allow the company to more accurately address its current waste practices and shape future policy. The strongest waste policy McDonald's could implement would be Zero Waste based, which would eliminate trash flow to landfill and only include recycling and composting as waste disposal options at applicable restaurant locations. According to the Zero Waste International Alliance (ZWIA), the goals of Zero Waste make up three parts:

> 1) "Zero Waste is a goal that is ethical, economical, efficient, and visionary, to guide people in changing their lifestyles and practices to emulate sustainable natural cycles, where all discarded materials are designed to become resources for others to use."

2) “Zero Waste means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them.”

3) “Implementing Zero Waste will eliminate all discharges to land, water or air that are a threat to planetary, human, animal or plant health.” [53]

ZWIA has also published Zero Waste Business Principles, which can be seen in Table 6 below. Most importantly to McDonald’s, and perhaps most challenging, is the principle of Zero Waste to landfill or incineration. This would involve a great deal of coordination at both the corporate level and individual restaurant level.

While not all of these specific principles can be achieved or are applicable to all McDonald’s restaurant locations, some of the individual principles and aspects of the goal can be implemented to reduce its overall waste to landfill.

Table 6: List of Zero Waste Business Principles (Source: ZWIA “ZW Business Principles” Zero Waste International Alliance: Working Towards a World without Waste. April 2005. http://zwia.org/standards/zw-business-principles)

Principle
Commitment to the Triple Bottom Line
Use of the Precautionary Principle
Zero Waste to Landfill or Incineration
Take-back Products and Packaging
Buy Reused, Recycled, and Composted
Prevent Pollution and Reduce Waste
Highest and Best Use
Economic Incentives for Customers, Workers and Suppliers
Products or Services Sold Are Not Wasteful or Toxic

Water

There is a growing interest in the connection between energy and water consumption worldwide. For example, one of the main product suppliers to McDonald’s, Coca-Cola, has recently undergone a major water reduction program as part of its sustainable, risk reduction strategy for the future. By reducing a restaurant’s water consumption, McDonald’s will be able to reduce their energy consumption, as well, through a reduction in energy used to power the water pumps and SHW system. One of the basic examples of a simple water efficient strategies utilized in some locations already, including the LEED Volume base scenario, is to use a water efficient sprayer aerator for their dish cleaning space. For example, the Food Service Technology Center suggests the use of a low-flow pre-rinse sprayer with a flow rate of 1.6 gallons per minute or less, which can save roughly 0.5 therms or 60 gallons per hour used.[54] While there are several basic water reduction strategies, if McDonald’s aims to take a stronger stance in sustainability, they should work towards Net Zero Water. According a report by the Living Building Institute, Net Zero Water can be defined as-

> “One hundred percent of occupants’ water use must come from captured precipitation or closed-loop water systems that account for downstream ecosystem impacts and that are appropriately purified without the use of chemicals.” [55]

The report explains the types of decentralized water system technology necessary to reach Net Zero Water, including rainwater harvesting, grey water reclamation and reuse, and wastewater treatment and

reuse. However, these technologies have been highly debated by building designers and health and safety experts, according to a presentation by USGBC.

The Food Service Technology Center describes the technologies below as their top recommendations for water conservation.

Table 7: Water Consumption Measures (Source: FSTC. "Water Conservation Measures for Commercial Food Service". FSTC: Save Water. 2010. http://www.fishnick.com/savewater/bestpractices/Water_Conservation_in_CFS.p)

Topic Area	Technologies
Refrigeration	- Air Cooled Ice Machines, not water cooled: A 500 lb per day water cooled machine can use nearly 100,000 gallons of water more per year than a air cooled equivalent. In terms of operating cost, the air-cooled machine saves $700 per year!
Water Heater	- Regularly Inspect Temperature Pressure Relief (TPR): This device can fail over time, allowing hot water to leak unnoticed.
General	- Use Water Brooms instead of Nozzles: Up to 5.0 gpm savings and more efficient cleaning compared to a single stream spray nozzle or an industrial sprayer. - Fix All Leaks[56]

Kitchen Equipment

As has been explained throughout the report, the scenario model and analysis suggest that it will not be possible for a McDonald's restaurant to reach a Net Zero Energy level without significantly changing the kitchen load. While not evaluated in this report, there are several technologies McDonald's can improve upon to lower its kitchen heating load, and therefore the electricity consumed. The appliances where more heat could be recovered are:

1) Coffee maker

2) Upright toaster

3) Heated landing zones

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Appendices

Appendix A- Duke Student Team Biographies

Emily Conner is a Master's of Environmental Management candidate with a concentration in Energy and Environment. She is also a graduate fellow and certificate candidate in the Center for Sustainability and Commerce. Emily's interests include energy efficiency and corporate and industrial sustainability. Her interdisciplinary background consists of policy, economic, basic legal, and environmental studies. Emily is currently working with McDonald's USA, LLC as a student consultant for her Master's Project focusing on designing and modeling a Net Zero Energy restaurant. Previous employers include Hitachi Consulting's Environmental Sustainability Solutions, Duke University's Energy Initiative, and the U.S. Department of Commerce's Sustainable Manufacturing Initiative. She received a Bachelor of Arts in Interdisciplinary Studies, specifically Communications, Law, Economics, and Government, from American University in Washington, DC. After graduation, Emily will be working with Booz Allen Hamilton in Washington, DC as a Consultant in their Infrastructure, Energy, and Environment team.

Maria Ramirez-Millan is a second year Master's of Environmental Management candidate with a concentration in Energy and the Environment at Duke University. Maria is also completing a Sustainable Systems Analysis certificate, which has allowed her to gain corporate sustainability and life cycle analysis skills, while consulting on real industry projects for Fortune 500 corporations. Her interests are focused on value chain sustainability, sustainable business strategies, energy management, consulting and environmental management. Maria obtained her bachelor degree from the Pontificia Universidad Javeriana in Bogota, Colombia where she majored in Industrial Microbiology. Then Maria spent a year doing research at the Environmental and Civil Engineering Department at the Massachusetts Institute of Technology. Before starting grad school, she served for a year as the Director of Research and Quality at Groncol, a company specializing in green roofs. At Duke, she has been able to gain expertise in project management, sustainable business strategies and energy project development. At Duke she also worked on her master's project that aimed to recommend technologies and methods required for McDonald's to design and implement a showcase "Net Zero Energy" restaurant.

Lane Wallace graduated from University of North Carolina at Chapel Hill in 2007 with a BS in Business Administration from Kenan-Flagler and a BA in Public Policy Analysis. She worked in real estate for two years in green development and marketing. Due to the recession, she switched paths from green buildings to improving existing structures. She briefly interned in energy efficiency installations before moving into renewable energy (RE). She started in the sales department for a medium-sized RE installer in Asheville, NC. She segwayed within the company to the design department where she primarily designed and estimated solar electric and solar hot water systems. She also worked on a project that successfully created a neutral carbon footprint for the office (not including commuting). After a brief travel adventure, she moved to Raleigh, NC, where she started a branch sales office for the company. She left the branch successfully running to pursue her Masters at Duke.

Appendix B- McDonald's Sustainability Highlights

Figure 13: Global Sustainability Highlights Graphic (Source: McDonald's. "McDonald's 2012 Global Sustainability Highlights". About McDonald's. 2013. Pages 5-6. http://www.aboutmcdonalds.com/content/dam/AboutMcDonalds/Sustainability/Progress%20Snapshot/2012SustainabilityH)

Appendix C- Net Zero Ideal Scenario Components

Net Zero Ideal Scenario	
Building area	**NZE parameters/technology**
Roof Insulation	R-100
Walls Insulation	R-60
Windows	Alpen 9H-9L Super windows
Light fixtures interior	All LED following specifications of LEED Cary
Light fixtures exterior	Removed load of light poles and façade lighting (Will be powered by solar DC) and changed menu boards to LED
Service Hot Water	Heat Reclaim System on fryers and condenser Units
Ventilation	Added Capture Jet® technology and VARI-VENT systems
HVAC design	Geothermal System proposed

Appendix D- Green Building Certification Detailed Overview

Living Building Challenge and Net Zero Energy Building Certification Overview

The Living Building Institute's Living Building Challenge has made its name as one of the most stringent certifications on the market. In general the Challenge takes a holistic look at a building's footprint, its purpose, and its complete life cycle impact on the environment and the people who interact with it. There are seven areas of focus in the Challenge: Site, Water, Energy, Health, Materials, Equity, and Beauty, which are subdivided into twenty 'imperatives'. While the complete Challenge takes roughly one year from registration to completion, to ensure certification based on actual performance, and involves completing a certain number of 'imperatives' (or spheres of influence) for the building type. [57] For more details on the Challenge, see the Living Building Institute's *Living Building Challenge 2.1* program document.

If a building project is mainly focused on energy consumption, then they may opt for the Energy Petal Certification, which focuses on the Living Building Institute's Net Zero Energy Building Certification. The certification has only one goal: "One hundred percent of the project's energy needs must be supplied by on-site renewable energy on a net annual basis."[58] While combustion is typically not allowed on the site, one temporary exception is for natural gas cooking equipment in commercial kitchens.[59] On top of this, the certification also mandates the following four 'imperatives' be completed: Limits to Growth, Rights to Nature, Beauty + Spirit, and Inspiration + Education.[60]

LEED and the Volume Program Overview

The U.S. Green Building Council (USGBC) is a nonprofit, member based organization founded in 1993. There are currently 77 chapters, 13,000 member organizations, and roughly 188,000 accredited professionals part of the USGBC community. Its main task has been as an international third party green building certification body with the Leadership in Energy and Environmental Design (LEED) program. To date, 10.5 billion square feet of space has been LEED certified by the USGBC. The USGBC announced the release of LEED v.4 at the end of 2013, an updated version from the most recent LEED 2009. [61]

To allow for flexibility for space utilization type, there are nine types of rating systems for various building spaces, including school and hospital specific systems. The main two rating systems are Building Design and Construction and Building Operations and Maintenance, or rather those systems for new buildings/major renovations and existing buildings. Within each of these rating systems, there are five main categories in which building designers can achieve credits: sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality. Two bonus categories included in most rating systems are innovation in operations and regional priority credits, which vary based on the site location and credits its region decides are most important. The number of credits a project achieves will determine which level of certification the design achieves: certified, silver, gold, or platinum. [62]

Launched in 2010, LEED announced a new rating system for buildings that are produced in high volume with little variance called 'LEED Volume'. The system is ideal for economies of scale and best for organizations that certify more than 25 projects within three years with the same building type. There are four phases for LEED Volume building certification. First, a project must be registered as a general LEED project under either the commercial interiors or new construction and major renovations rating systems for both general and retail buildings. Second, a conceptual building design, also known as a prototype, must be registered. Third, the prototype goes through pre-certification with the Green Building Institute for required components. The final phase is ongoing certification of the building after

construction is completed. An organization can certify multiple building prototypes, each with its own set of pre-certified credits and design.

According to the company's annual report, McDonald's added 225 new restaurants in 2013.[63] The high number of new buildings and major reconstruction projects McDonald's undergoes each year makes it an ideal candidate for the LEED Volume program. By using the Volume program, McDonald's cuts costs and time for each certification earned. [64]

ASHRAE- Building Energy Quotient

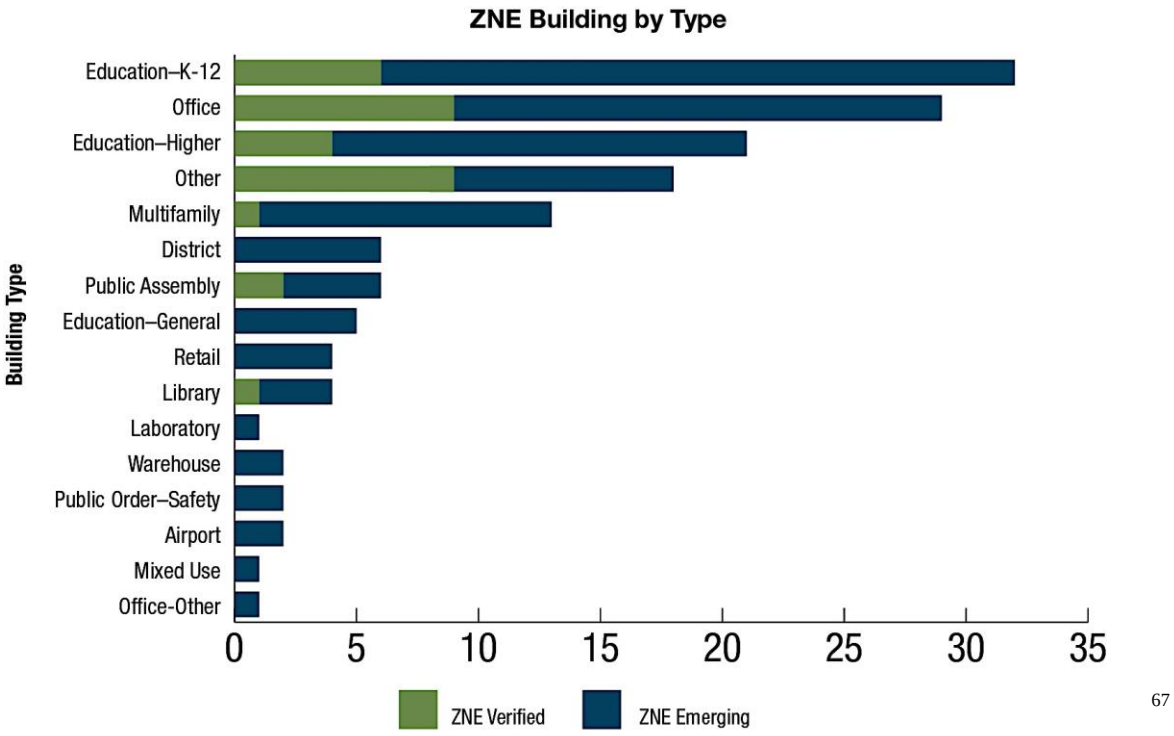
Building Energy Quotient (bEQ) is an energy-rating program sponsored by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). The program is split into two parts to evaluate different stages of building development- 'As Designed' (pre-construction) and 'In Operation' (post-construction). Buildings or building models are given a letter grade A+ to F based on a list of criteria and as evaluated by an assigned professional. The highest designation, A+, is reserved for those buildings shown to consume 'Zero Net Energy'.[65] Building analysis for certification is separated by building types, including 'fast food', retail, etc. Currently, the 'fast food' type is only available through the 'In Operation' evaluation.

Appendix E: Net Zero Energy Definitions.

NREL's Net-Zero Energy Building Definitions [66]
Net Zero Site Energy: A site NZEB produces at least as much renewable energy as it uses in a year, when accounted for at the site.
Net Zero Source Energy: A source NZEB produces (or purchases) at least as much renewable energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to extract, process, generate, and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers based on the utility's source energy type.
Net Zero Energy Costs: In a cost NZEB, the amount of money the utility pays the building owner for the renewable energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.
Net Zero Emissions: A net zero emissions building produces (or purchases) enough emissions-free renewable energy to offset emissions from all energy used in the building annually. Carbon, nitrogen oxides, and sulfur oxides are common emissions that ZEBs offset. To calculate a building's total emissions, imported and exported energy is multiplied by the appropriate emission multipliers based on the utility's emissions and on-site generation emissions (if there are any).

Table 8: Source- Adapted from U.S. Department of Energy's National Renewable Energy Laboratory (NREL). "Net Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options." June 2010.
http://www.nrel.gov/sustainable_nrel/pdfs/44586.pdf

Appendix F: Net Zero Energy Buildings by Type



[67]

Image Source: New Buildings Institute. "Graphics for 2014 Getting to Zero Status Update" New Buildings Institute: 2014 Getting to Zero Status Update. *2014.* *http://newbuildings.org/2014-zne-graphics*

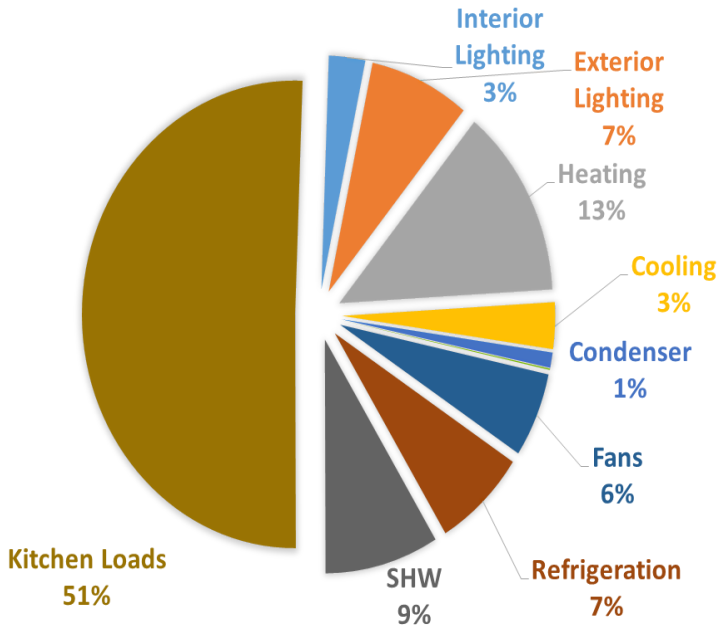
**No restaurants are represented in this graph, as there are no restaurants verified or emerging as Net Zero Energy.*

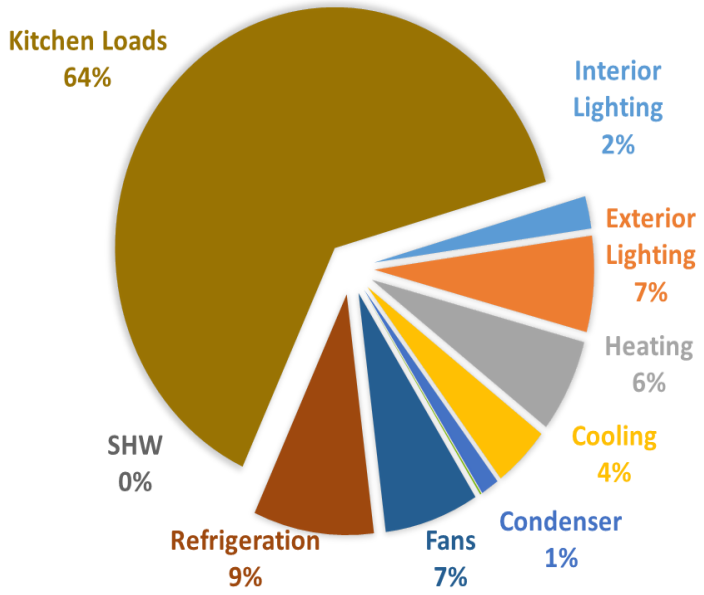
Appendix G: Solar Market Incentives

Incentive Title	Description	Rate
Investment Tax Credit (ITC)- Federal	"Eligible solar energy property includes equipment that uses solar energy to generate electricity, to heat or cool (or provide hot water for use in) a structure, or to provide solar process heat. Hybrid solar lighting systems, which use solar energy to illuminate the inside of a structure using fiber-optic distributed sunlight, are eligible." [68]	30% of expenditures
Special Property Assessment for Solar Energy Systems	"Illinois offers a special assessment of solar energy systems for property-tax purposes. For property owners who register with a chief county assessment officer, solar energy equipment is valued at no more than a conventional energy system. Eligible equipment includes both active and passive solar-energy systems." [69]	*This incentive was not included in analysis, since its value is site specific.

Table 9: Sources: U.S. Department of Energy. "Federal: Business Energy Investment Tax Credit (ITC)" DSIRE. March 13, 2014. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F and US Department of Energy. "Illinois: Special Assessment for Solar Energy Systems". DSIRE. July 22, 2012. http://www.dsireusa.org/solar/incentives/incentive.cfm?Incentive_Code=IL01F&re=1&ee=1

Appendix H: Net Zero Energy Scenario Load Results





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