Design of a Cost-effective, Modular

and

Energy-efficient Home

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Abstract

The 'green revolution' has recently taken over the building industry with increasing number of buildings implementing environmentally friendly and sustainable technologies to minimize costs as well as reduce environmental impact. The concept of green building however has been mostly associated with higher costs and remains popular mostly amongst well-to-do clients. According to the EIA Annual Energy Outlook, 2017, the residential sector in U.S. makes up 20% of the total energy consumption and is greater than the contribution by the commercial sector (18%)[1]. However, high upfront costs have been identified as a significant barrier to many households investing in green properties or greening their existing homes.

This project seeks to address the growing problem of a lack of affordable, energy efficient, and environmentally-sustainable housing in partnership with Harvest Energy Solutions in Jackson, Michigan. This is achieved through the design of a prototype of modular single-family home that is affordable and energy-efficient. The methods used in the study were firstly architectural design of a single module of a home, simulation of energy performance for a baseline vs. traditional model, and finally constructing a cost model. It seeks to create awareness among architects, engineers and developers about the growing need for sustainability and the energy savings that can be achieved alongside affordability.

[1] (2018, February 6). Annual Energy Outlook 2018 with projections to 2050. *U.S. Energy Information Administration*. Retrieved from https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf

Contents

1.0 Introduction

There has always been a challenge with designing a home that not only provides improved quality of life options for low income families, but is also sustainable and energy efficient, utilizing renewable energy products and innovative methods for conservation and efficiency. There are several roadblocks like high energy costs, inefficient appliances, high upfront investment in energy efficiency and lack of comprehensive low-income programs etc. that currently persist[2]. Therefore, there is a need for energy-efficient housing that reaches out those sections of the society that currently opt for cheaper living options simple on grounds of affordability. Since the existing pool of energy-efficient housing is simply too cost-intensive for them, their budgetary constraints simply outweigh both the long-term economic and health benefits of sustainable housing.

Therefore, the project draws inspiration from two key factors, which are energy-efficiency and affordability. The home should be sustainable and energy efficient, utilizing cutting-edge renewable energy products and innovative methods for conservation and efficiency; and at the same time should be modular, customizable, and most importantly, economically feasible for low income populations or those living or wishing to live in remote environments and without access to utilities.

There has been a recent spur in the demand of prefabricated homes, especially manufactured homes that do not require any on-site construction and to some extent of modular homes. However, the "Tiny Home" trend has a very small target market compared to regular houses and the traditional manufactured and modular homes haven't witnessed much growth and innovation in the green industry[3]. Individuals, couples, and families want reasonable as well as affordable accommodations, and that is one of the goals of this project since regular "green" or "net-zero" homes on the market are simply not affordable.

With strides being made in material science and technology, and costs coming down for renewable energy products such as solar PV and batteries, a product such as this has the potential to become a realistic option.

1.1 Research Objectives

1) Make energy-efficient housing more affordable.
2) Achieve a selling-price of the home under $100,000

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[2] Low-Income Energy Efficiency Programs. *U.S. Department of Energy*. Retrieved from https://www.energy.gov/sites/prod/files/2017/03/f34/bbrn_Summary_Low-IncomePrograms_022317.pdf

[3] Kulp, K. (2017, February 2). Tiny houses grow in popularity, yet drawbacks abound. *CNBC*. Retrieved from https://www.cnbc.com/2017/02/02/tiny-houses-grow-in-popularity-yet-drawbacks-abound.html

3) Explore technologies and material that are both cost-effective and sustainable.
4) Disrupt the traditional housing market

1.2 Research Methodology

1) Background research on market feasibility and target audience.
2) Architectural Design of a single modular unit on AutoCAD and Revit Architecture
3) Energy modelling of the baseline design with traditional materials and configuration on e-QUEST to assess energy performance and identify opportunities with regards to factors such as renewable energy generation, heating and indoor air quality, building materials and so on.
4) Identification of energy efficient and cost-effective products and materials to be installed.
5) Energy modelling of the redesigned unit incorporating the energy-efficient products and materials on e-QUEST to assess energy performance and analyze achieved savings
6) Calculation of the final market price of the unit.
7) Assessment of the environmental impact of materials and technologies used in the prototype.

1.3 Limitations and Assumptions

1) The house has been designed as per the climatic conditions of Ann Arbor, Michigan and hence is mostly applicable to colder climates.
2) The research details out mostly architectural and design interventions.
3) The research mostly deals with energy consumption, and no other environmental impacts.
4) The energy performance has been studied only for the operational phase and not the pre-use phase.
5) The human energy is taken as zero for all calculation purposes.

2.0 Market Research

The first step in the project was to narrow down a market. Ann Arbor, MI was chosen as the target market for the housing design based on the following considerations:

1) The client is based out of Jackson, MI and hence wanted to target a nearby market.
2) The client's current work in renewable technologies is catered towards the living conditions in cold weather.
3) High growth potential – According to an article by Clickondetroit.com, the Ann Arbor Metropolitan Area witnessed Michigan's largest percent population increase from 2015 to 2016[4].

To understand the feasibility and marketability of the project scope, a thorough research of the existing housing market in Ann Arbor was conducted to identify opportunities and our target audience.

2.1 Existing Market

To identify the opportunities for sustainable and cost-effective housing, several parameters such as housing costs, rent, median income, demographics were compared based on existing literature and research about the city.

According to a study by NeighborhoodScout, housing in Ann Arbor with a median cost $390,329 is not only one of the most expensive in Michigan, but in the entire country; and is also one of the highest appreciating real estate markets in the whole nation.[5] Hence, the Ann Arbor market clearly poses a potential for more affordable housing options. The charts below depict some of these trends in from the study about the Ann Arbor market.

[4] Haddad, K. (2017, March 23). US Census: Ann Arbor area sees state's largest population increase in 2016. *ClickOnDetroit*. Retrieved from https://www.clickondetroit.com/news/michigan/ann-arbor/us-census-ann-arbor-area-sees-states-largest-population-increase-in-2016

[5] Ann Arbor, Mi Appreciation Rate Trends and Housing Market Data. (2018). *NeighborhoodScout*. Retrieved from https://www.neighborhoodscout.com/mi/ann-arbor/real-estate

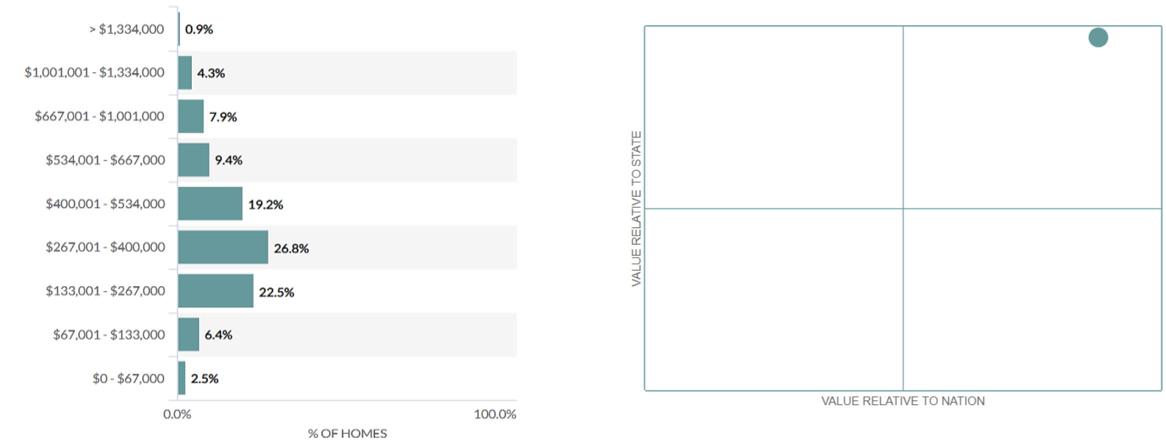

Figure 2.1(a): Percent of homes by median price. Figure 2.1(b): Ann Abor relative median home price. *Source: https://www.neighborhoodscout.com/mi/ann-arbor/real-estate*

These are the trends on home prices, but what really makes the Ann Arbor market worth the investment is the demographic trends. From Figure 2(a) below, we observe that the median household income of Ann Arbor reduces closer to the downtown, and Figure 2(b) tells us the median home price on the other hand increases as one gets closer to the downtown. This paradox can very well be explained by the huge student and youth population associated with the University of Michigan. This also creates a huge potential for low-income housing.

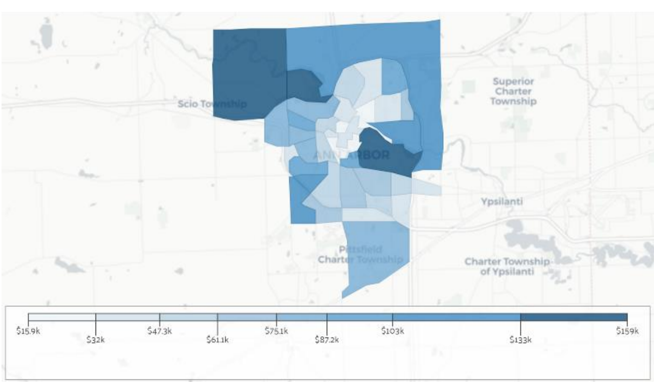

Figure 2.2(a): Ann Abor median household income distribution *Source: https://www.neighborhoodscout.com/mi/ann-arbor/real-estate*

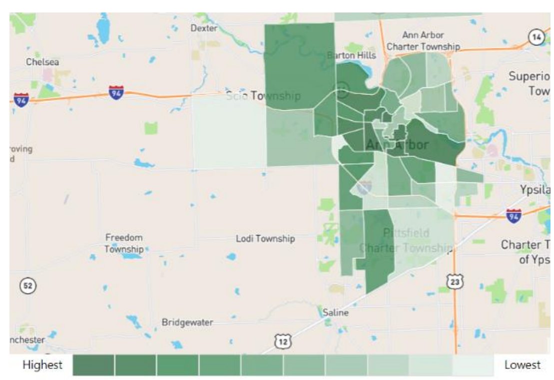

Figure 2.2(b): Ann Abor median home price distribution *Source: https://www.neighborhoodscout.com/mi/ann-arbor/real-estate*

2.2 Target Audience

There is a clear opportunity in the heart of Ann Arbor, but there also needs to be an understanding of whom to design for, i.e., our target audience. Figure 2.3 represents the income distribution in Ann Arbor compared to the entire country, and we can see that the wages are distributed more unevenly than the nation too. Almost 25% of the population earns less than $10,000 and almost half of the population earn below $50,000 annually.

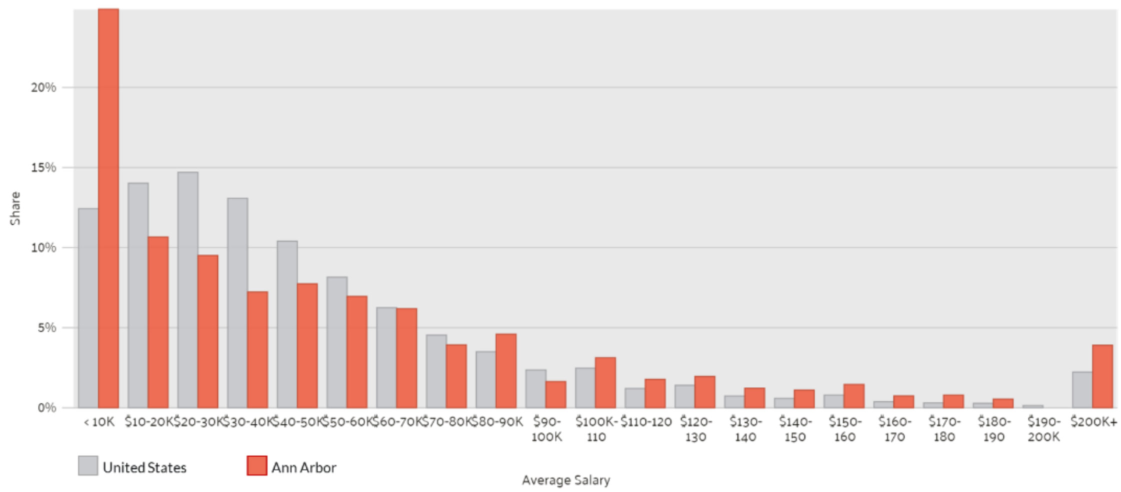

Figure 2.3: Income distribution in Ann Arbor. *Source: https://datausa.io/profile/geo/ann-arbor-mi/*

Figure 2.4 depicts the share of population living below the poverty line and also provides an interesting insight. The 18-24-year-old age group disproportionately represent almost 35% of all the people living in poverty, followed by the 25-34-year-old age group at around a distant 5%. Clearly, the younger section of the population isn't faring well financially. Additionally, 23.4% of the city's population live below the poverty line and is higher than the national average of 14%.[6] Therefore, the target audience this design will target is the younger section of the Ann Arbor population, more specifically, **18-29-year old age group.**

[6] Data USA: Ann Arbor, MI. Retrieved from https://datausa.io/profile/geo/ann-arbor-mi/#category_wages

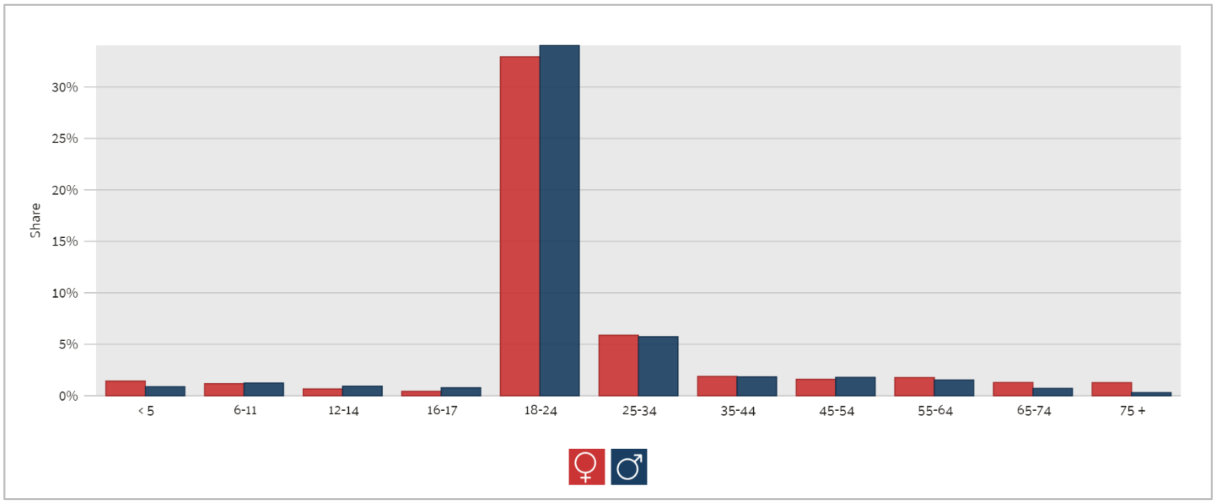

Figure 2.4: Poverty by age and gender. *Source: https://datausa.io/profile/geo/ann-arbor-mi/*

3.0 Architectural Design

Keeping in mind our target users, market feasibility as well as client requirement, the house needed to be designed that considers all three factors and meet all of the objectives described in Chapter 1. The first step was to explore the different technologies to approach this problem, which are discussed below:

3.1 Technologies Considered

Since the primary motivation for the client was to keep the cost under $100,000, the first step was to determine a technology that could drastically reduce the building costs so that we can invest more in attaining energy-efficiency. To achieve this, the following technologies were considered which are discussed in detail further:

1) Container homes
2) Modular Housing

3.1.1 Container homes

Container homes as their name suggests are made out of the steel shipping containers used to transport goods. Cost-effectiveness is the primary benefit of making homes out of containers, and the price of these containers can range anywhere from $1,400 to $4,500[7]. Container homes also come with a significant environmental advantage as in essence, they are recycled material themselves built from discarded shipping containers. Finally, the construction process is a lot faster since it just requires repurposing and retrofitting already existing steel walls and roof[8].

3.1.2 Modular Housing

Modular homes are basically homes whose certain components are manufactured in factory, transported onto the site and assembled there to form the complete unit[9]. These 'modules' can be either building components like walls, floors, roofs etc. or entire individual units transported onto

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[7] Stribling-Kivlan, E. A. (2017, November 9). Why the Shipping Container Home Movement Is Getting So Big. *Forbes*. Retrieved from https://www.forbes.com/sites/forbesrealestatecouncil/2017/11/09/why-the-shipping-container-home-movement-is-getting-so-big/#5649066e2c21

[8] Strain, S. (2017, February 3). Why Shipping Container Homes Are an Eco-Living Dream. *Green Future*. Retrieved from https://greenfuture.io/sustainable-living/why-shipping-container-homes-are-an-eco-living-dream/

[9] Wickell, J. (2018, November 2). What are Modular Homes vs Manufactured? *The Balance*. Retrieved from https://www.thebalance.com/what-are-modular-homes-1797807

the site and assembled to form a larger unit or group housing. For this project, the design described in section 2.2 can be understood as one module which will be transported onto the site. Modules also facilitate scalability in the sense that if required, more modules of the design can be transported and assembled together for a larger unit.

Modular housing essentially reduces costs since it standardizes the design and minimizes the number of players involved in the home building process. Moreover, this methodology is quick and substantially reduces the construction time compared to traditional homes[10].

3.2 The Design

The idea behind the design of the house was to keep the concept of modularity and scalability as the priority. As described before, the house is designed out of a 40ft. X 12ft X 8.5 ft. container which constitutes our 'module'. The design described here is of a single module with bare minimum requirements which will be manufactured off-site in a facility and then later transported via trucks to the actual site of the project.

In Figure, you can see the single module consisting of a living area, kitchen, bedroom and a bathroom. A small open entry porch and balcony adjoining the room has also been provided to ensure provision for outdoor exposure and ventilation.

Figure 3.1: Architectural rendering of the design

The modularity is also useful in terms of scalability of the design. The design described here is that of a single module, but can be scaled up if the client needs to sell bigger space or increase the number of bedrooms etc. (Figure 3.2) Each container or module will be manufactured in the facility

[10] Barnett, E. (2018, August 2). Modular Construction: A Housing Affordability Game-changer? *Sightline Institute*. Retrieved from https://www.sightline.org/2018/08/02/modular-construction-a-housing-affordability-game-changer/

and later transported module by module on site where they will be assembled to make up the complete unit.

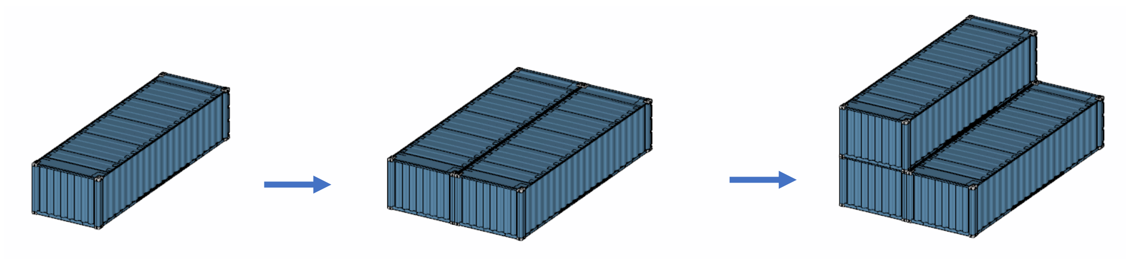

Figure 3.2: Scaling in modular construction

2.1.3 Energy Efficiency considerations

Compactness

Another benefit we get from the container module is passive energy efficiency. The higher the compactness of a building, the more energy-efficient it will be. More specifically, the lower the surface area to volume ratio of a building, the better it will perform it terms of passive energy efficiency[11].

The surface area of our module = 2(8.5*12 + 8.5*40 + 12*40) = 1844 ft^2

The volume of our module = 8.5*12*40 =4080 ft^3

Therefore, the compactness of our module = **0.45**, which makes it quite energy-efficient.

Window Placement

Being in cold climate, heating takes up most of the annual energy consumption (see section 2.3). Therefore, we need to maximize solar gain to offset whatever heating load we can. To account for this, significant amount of glazing is to be provided in the south façade which receives the most direct sunlight in the northern hemisphere[12]. One of the longer sides of the house has been provided with significant amount of glazing which when placed on the site should be facing within 30 degrees of true south.

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11 Thorpe, D. (2016, November 22). How Changing Building Shape and Form Can Slash Energy Use. *Energy Central*. Retrieved from https://www.energycentral.com/c/ec/how-changing-building-shape-and-form-can-slash-energy-use

12 Passive Solar Home Design. *Energy.gov*. Retrieved from https://www.energy.gov/energysaver/energy-efficient-home-design/passive-solar-home-design

4.0 Energy Performance Analysis

We have the design, but we also need to see how we can optimize it best to reduce energy consumption. This section examines the energy performance analysis of the design described before by first simulating a baseline model of the design considering traditional building configurations first, and then simulating the same model by changing the traditional configuration with energy-efficient ones. The whole simulation has been done in eQUEST, a comprehensive building energy simulation tool (Figure 4.1). It should be noted that we are only simulating the energy performance of the operational phase and not the energy embodied in the building materials (pre-use phase).

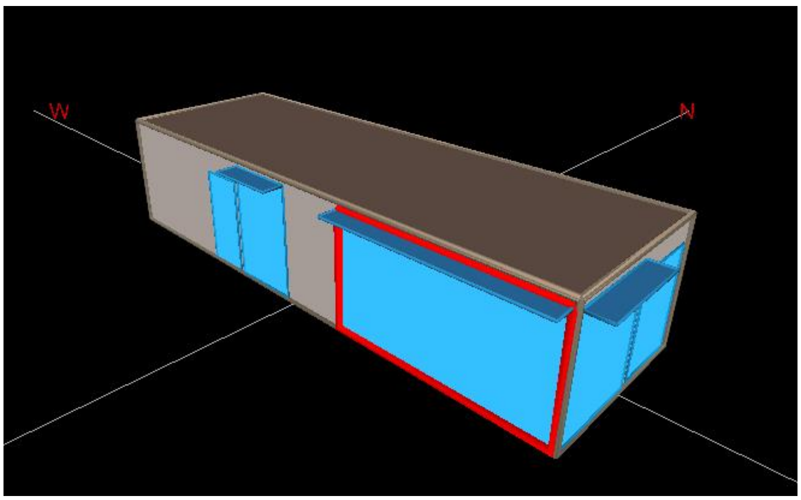
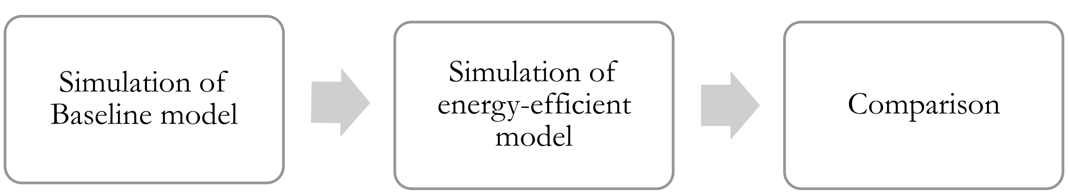


Figure 4.1: eQUEST Energy Model

The entire energy analysis process can be summarized as follows:



4.1 Baseline vs. Energy-efficient

While constructing the model in eQUEST, several parameters were inputted. Table 1 summarizes the key parameters that differentiate the baseline from the energy-efficient model:

Table 4.1: Baseline vs. Energy-efficient parameters considered

	Baseline	Energy-efficient
Orientation	Random	North-south
Heating	Natural gas	Electricity
Envelope material	Steel	Steel
Wall insulation	None	Polyurathrene Insulation
Roof insulation	None	Polyurathrene Insulation
Door frame	uPVC	uPVC
Door glass	Single clear tint	Double-glazed low-E insulated
Window frame	uPVC	uPVC
Window glass	Single clear tint	Double-glazed low-E insulated
Shading devices	None	18" overhangs + Horizontal Blinds

4.2 Results

Following graphs show the energy consumptions for the baseline vs. energy-efficient models. For detailed report see Appendix B.

Baseline model

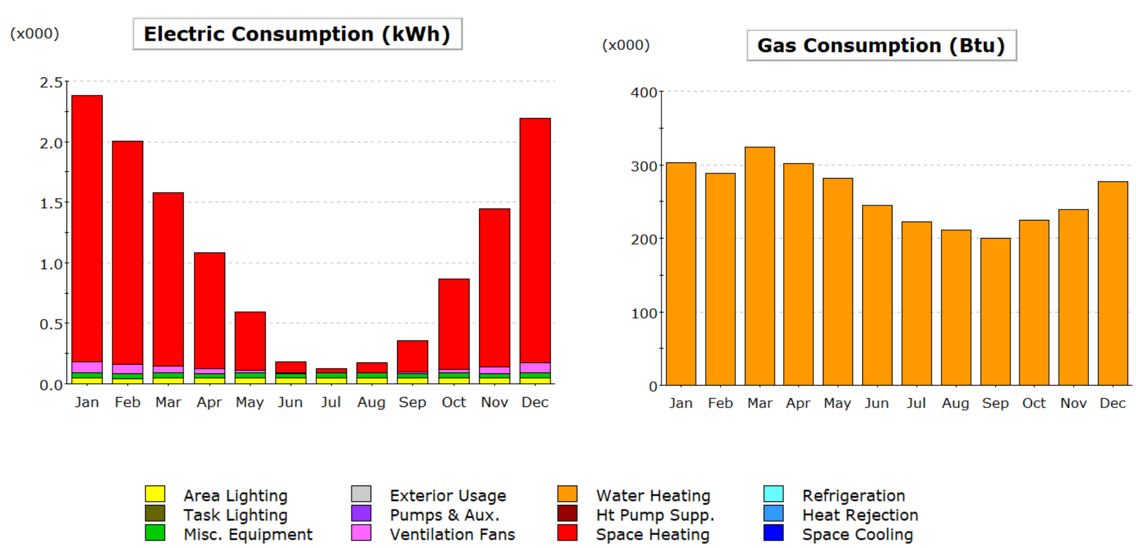


Figure 4.2: Baseline model simulation results

From the model results, the following data was obtained:

- Annual electric consumption = 12,980 kWh
- Annual gas consumption = 3,116,500 Btu = 913 kWh
- Total Annual energy consumption = **13,893 kWh**

Energy-efficient model

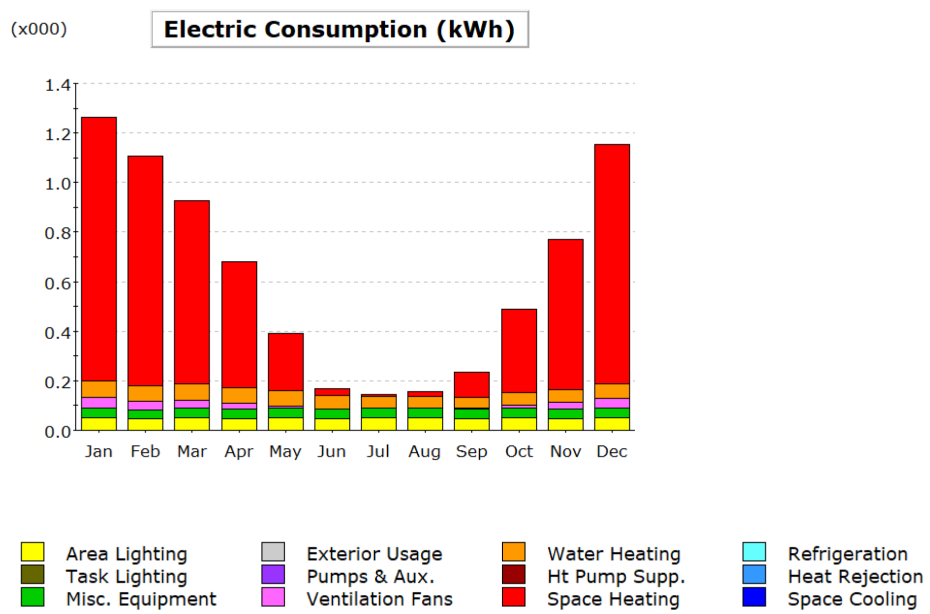


Figure 4.3: Energy-efficient model simulation results

From the model results, the following data was obtained:

- Total Annual energy consumption = **7,480 kWh**

Note that there is no natural gas involved sine we are using electricity for heating in the energy-efficient model.

Energy and cost Savings:

Annual energy saved in adoption of the energy-efficient model = 13,893 kWh – 7,480 kWh = 6,503 kWh or almost **47% in energy savings.**

To estimate the cost savings, we need to consider the energy values of electricity and natural gas separately since they are billed at different rates. According to the U.S Energy Information

Administration (E.I.A.), the average residential electricity rate in Ann Arbor is 14.13¢/kWh and the residential natural gas price $13.39 per thousand cubic feet as of August 2018[13].

1) Total annual cost for the baseline model = 12,980 kWh ($0.1413) + 3,115.3/1000 ft.^{3} ($13.3) [3,115.3 ft.^{3} of natural gas produces 913 kWh of energy].
   Total annual cost for the baseline model = $1,875.5

2) Total annual cost for the energy-efficient model = 7,480 kWh ($0.1413) = $1,056.924

Therefore, the annual cost savings achieved through adoption of the energy-efficient model = $1,875.5 - $1,056.9 = $818.5 or almost 44% **savings in cost.**

It should be noted here that at first, $818.5 doesn't seem like too significant an amount in the context of building costs. However, this is because of the small size of the house which is just 12ft. by 40 ft., but when you scale up the size with more modules, the cost savings can be huge.

To put this into perspective, the per square foot savings will equal $818.50/12*40ft. = $1.7/sq. ft. savings. The median home size in Ann Arbor is 1,728 sq. ft., so scaling this value in purely linear terms would mean saving 1,728*$1.7 = $2937.6 roughly annually for the median sized property constructed using this design[14]. This is enough to cover monthly expenses like internet, water and possibly even car insurance.

4.3 Solar Offset

To estimate the solar potential for the house and location (Ann Arbor, MI), NREL's PVWatts calculator (https://pvwatts.nrel.gov/) was used[15]. The following results were obtained by using a 6kW DC system size from PVWatts:

[13] (2018, February 6). Annual Energy Outlook 2018 with projections to 2050. *U.S. Energy Information Administration*. Retrieved from https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf

[14] Ann Arbor Home Prices & Values. Zillow. Retrieved from https://www.zillow.com/ann-arbor-mi/home-values/

[15] PVWatts. NREL. Retrieved from https://pvwatts.nrel.gov/

Table 4.2: PVWatts Solar Potential calculation results

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.28	355	50
February	3.42	465	66
March	4.45	634	90
April	5.31	728	103
May	5.76	794	112
June	6.31	820	116
July	6.59	863	122
August	5.96	783	111
September	5.11	655	93
October	3.78	526	74
November	2.72	385	54
December	1.91	292	41
Annual	**4.47**	**7,300**	**$ 1,032**

Therefore, the maximum potential that can be achieved = 7,300 kWh.

From section, 2.2, the estimated annual energy consumption = 7,480 kWh which leaves just 180 kWh gap. And just through solar, we are able to achieve an almost net-zero design.

For detailed report of the results, see Appendix

Payback consideration

Considering the financial feasibility of installing solar, we need to understand the payback period of investing in solar. From Table 2, we see that annual dollar value of the generated solar is $1032.

From Section 5.0 Table 3, the cost of the solar panels comes out to be $5736 (excluding maintenance, transportation and installation). Hence, to achieve a payback for the cost of solar panels, it would take approximately $5736/$1032 = <u>5.6 years,</u> which is not a very long time.

5.0 Cost Calculation

To make the home an attractive option for the low-income group, the cost of the single module design had to be very effective such that the costs aren't increased substantially even if we scale up the house.

The cost calculation considers all the parameters necessary to obtain a selling price for the home including building components, manufacturing and transport. Most of the building components are based on the specifications considered while simulating the energy-efficient model, and the cost of solar panels is based on the product specified by the client. All the prices listed in the cost model are as of December 2018. The cost model does not consider the prices incurred during the operational phase of the home such as water, electricity, maintenance etc. The model also only considers baseline finishing's like flooring, roofing, wall paint etc. The costs of hardware, appliances, plumbing, HVAC etc. are also not included.

It should also be noted that the cost model is based on limitations and approximations made in the study, and the actual cost while building the design can vary. The final estimate of the price based on the cost model of the home comes out to be **$45,572**.

Table 5.1: Cost Model

Building Components						
Item	**Type**	**Quantity**	**Unit**	**Cost/unit**	**Cost**	**Certification**
Shipping Container	12' X 40'	1		$5,600	$5,600	
Windows - North	uPVC Double glazed low-E	2		$493	$986	Energy Star
Windows - West	Double Hung - low-E3 with argon	1		$179	$179	Energy Star
Fixed Panel Windows - South and East	LowE3 insulated glass	9		$125	$1,125	Energy Star
Entry Door	Sliding door - LowE3 insulated glass	1		$329	$329	Energy Star
Exterior door 1 - South	Sliding door -	1		$330	$330	Energy Star

	LowE3 insulated glass					
Exterior door 2 - West	Fiberglass Prehung Back Door	1		$256	$256	Energy Star
Interior Doors	Unfinished Prehung Interior Door	2		$60.98	$122	Energy Star
Railings	Pre-Built Rail - 6 ft	5		$49.97	$250	Energy Star
Roof sheathing		48	m^2	$0.12	$6	
Flooring	Reclaimed oak laminate flooring	37.6	m^2	$5.27	$198	
Polyurathrene Insulation		1151.74	m^2	$2.00	$2,303	
Interior Finishes						
Item	**Type**	**Quantity**	**Unit**	**Cost/unit**	**Cost**	
Particle Board		75	m^2	$7.30	$548	
Wall Paint		75	m^2	$2.14	$161	
Accessories						
Item	**Type**	**Quantity**	**Unit**	**Cost/unit**	**Cost**	
Blinds		19.44	m^2	$75.65	$1,471	
Low Efficiency Generator				$1,899	$1,899	
Solar Panels		24		$239	$5736	
Transportation/Manufacturing						
Item	**Type**	**Quantity**	**Unit**	**Cost/unit**	**Cost**	
Shipping the container module		37.5	miles	$2	$75	
Labor costs		480	ft^2	$50	$24,000	
				Total	**$45,572.48**	

Reflection

The combination of container and modular home technology as we have seen can significantly bring down the home ownership cost. This design will prove to be successful especially in regions where the income levels are not at par with the cost of living as seen in the case of Ann Arbor. With homelessness becoming a serious problem especially in big cities, the modular container home model can be brought in to tackle the affordable housing challenges. Beyond just ownership, the low cost of these homes means they can be rented out at much lower rates than their traditional counterparts to groups like students, low-income communities, refugees, hostel renters and so on.

In terms of sustainability, these homes are already built out of discarded shipping containers which would have otherwise gone to landfill, greatly reducing the environmental footprint. As evident from our study, these homes are capable of utilizing passive sustainable design as well as renewable technologies like solar like any traditional home. Overall, we can say that the modular container home technology can prove to be an effective market disruptor to traditional housing.

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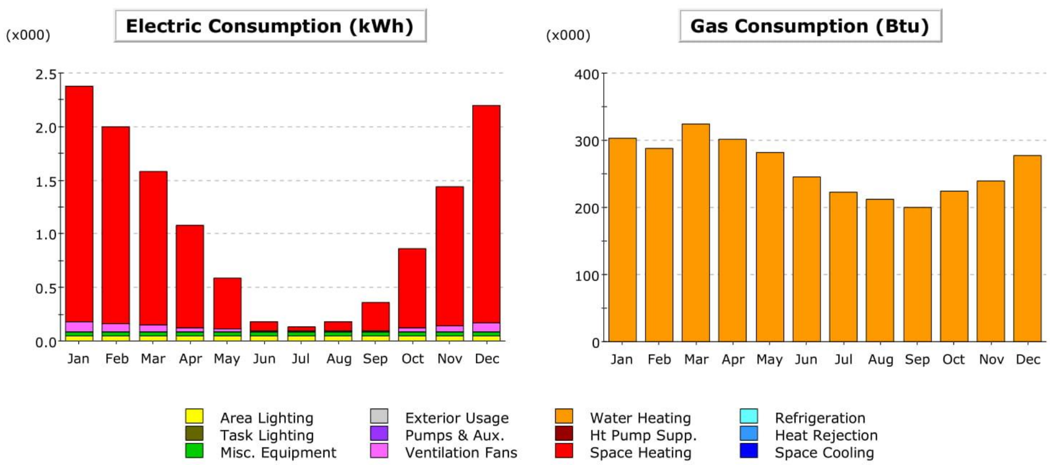
Appendices

Appendix A: House Plan

Appendix B: Simulation results – Baseline model

Project/Run: Base - Baseline Design | Run Date/Time: 11/21/18 @ 02:51



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	2.20	1.85	1.43	0.96	0.48	0.09	0.04	0.08	0.26	0.74	1.30	2.02	11.45
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.09	0.08	0.06	0.04	0.02	0.00	0.00	0.00	0.01	0.03	0.05	0.08	0.48
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.46
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.59
Total	2.38	2.00	1.58	1.08	0.59	0.18	0.13	0.18	0.36	0.86	1.44	2.19	12.98

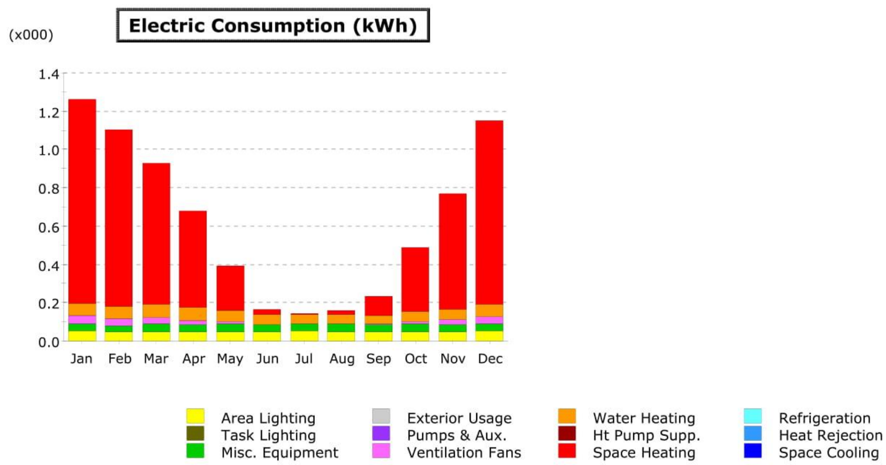
Gas Consumption (Btu x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	302.3	287.8	324.0	301.5	281.1	244.8	222.0	211.5	200.0	224.4	239.7	277.4	3,116.5
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	302.3	287.8	324.0	301.5	281.1	244.8	222.0	211.5	200.0	224.4	239.7	277.4	3,116.5

eQUEST 3.65.7173 | Monthly Energy Consumption by Enduse | Page 1

Appendix C: Simulation results – Energy-efficient model

Project/Run: Green - Baseline Design   Run Date/Time: 10/20/17 @ 12:07



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.06	0.92	0.74	0.51	0.23	0.03	0.01	0.02	0.10	0.34	0.61	0.96	5.53
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.06	0.06	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.05	0.05	0.06	0.67
Vent. Fans	0.04	0.04	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.23
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.46
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.59
Total	1.26	1.11	0.93	0.68	0.39	0.17	0.14	0.16	0.23	0.49	0.77	1.15	7.48

Gas Consumption (Btu)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													

eQUEST 3.65.7173   Monthly Energy Consumption by Enduse   Page 1