ILLINOIS INSTITUTE OF TECHNOLOGY

NET-ZERO IIT

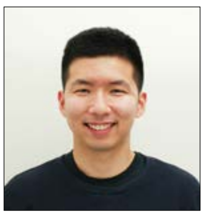
U.S. Department of Energy Race to ZERO
2016 Student Design Competition
24 March 2016

Table of Contants

1 | Team Qualification

Team Profile

The Net-Zero IIT townhouse is designed to be an affordable, energy efficient, and healthy home located in Chicago, IL. The interdisciplinary design team, made up of architects and engineers, will apply building science principles to achieve a solution that is high-performance, cost-efficient, structurally sound, and aesthetically pleasing. The design will meet both the requirements of the DOE Zero Energy Ready Home as well as the International Energy Conservation Code (IECC) 2012.



YunJoon Jung | Team Leader
Student, Architectural Engineering

As a leader of Net-0 IIT team, I served as a team organizer and did energy analysis, space conditioning & ventilation have been interested in building science, HVAC system, and building enclosure. I am dream in making building use zero in near future.

Julia del Pino Torres
Graduate student, Architectural Engineering
My primary responsibility in the DOE Race to Zero 2016 competition was designing units capable to achieve an excellent Indoor Air Quality (IAQ) and implement appliances that lead us to save energy, as well as designing, sizing, and implementing the hot water system. I've enjoyed this valuable experience and I'm looking forward to put in practice the knowledge acquired on the real market.

Dilip Kumar Erukulla
Graduate student, Architectural Engineering

I was part of Energy Analysis and Mechanical Design Team. I dream in becoming a Energy Engineer and work closely with High Performance Buildings.

Kyeore Lee
Bachelor of Architecture

I got involved in designing the townhouse and it was great opportunity for me to collaborate with engineering students.

Team Profile

Dongho Shin
Student, Architecture

My goal in this competition is to design environmental-friendly building with engineering students.

Naveen Sudhakaran
Master of Science in Architectural Engineering

My area of concentration was primarily in energy analysis, envelope durability and lighting design. I had a great experience and gained a few skills working in this project.

Xiaolong Wang
Ph.D student in Environmental Engineering

I worked on the financial analysis side of the project. I am currently interesting at geothermal heat pump systems and urban water systems. I am also doing research on energy efficiency policies.

Faculty Advisor

Brent Stephens, Ph.D.
Assistant Professor, Civil, Architectural and Environmental Engineering
Illinois Institute of Technology

Dr. Brent Stephens is an Assistant Professor of Architectural Engineering in the Department of Civil, Architectural and Environmental Engineering at Illinois Institute of Technology (IIT). He has a Ph.D. in Civil Engineering and an M.S.E. in Environmental and Water Resources Engineering, both from the University of Texas at Austin. He also has a B.S.E. in Civil Engineering from Tennessee Technological University. Dr. Stephens and members of his Built Environment Research Group at IIT (www.built-envi.com) conduct research on the intersections of energy and air quality in the built environment, primarily with field measurements in and around buildings. Their work continues to advance building science methods for assessing energy efficiency, indoor air quality, and environmental exposures within buildings. Dr. Stephens also teaches courses in Building Science, Building Enclosure Design, and Indoor Air Pollution at IIT.

Edoarda Corradi Dell Acqua, M.S.
Adjunct Professor, Civil, Architectural and Environmental Engineering
Illinois Institute of Technology

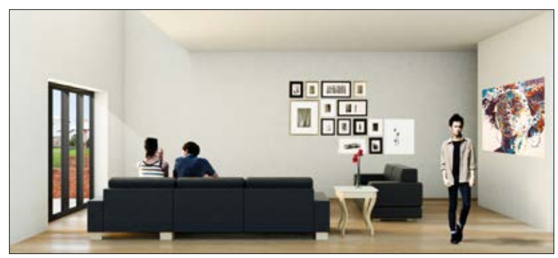
Edoarda Corradi Dell Acqua is an adjunct professor in the Department of Civil, Architectural and Environmental Engineering at the Illinois Institute of Technology. She has a M.S. in Architectural Engineering from the Illinois Institute of Technology and a M.S. in Architecture from the Milan Polytechnic. Her work experience in Milan and Chicago includes commercial and residential building design with Box Studios and integrated design with dbHMS. Her academic and professional background in both fields allowed her to develop a research interest, which lies at the intersection of architecture and engineering. She is also a board member of the Chicago Architectural Club (CAC), which promotes debates within contemporary theory and criticism in art and architecture. Edoarda Corradi Dell Acqua teaches Architectural Design, Engineering Graphics and the Capstone Senior Design class at the Illinois Institute of Technology.

Net-Zero IIT

The Net-Zero IIT Town House

The Net-Zero IIT townhouse is designed to be an affordable, energy efficient, and healthy home located in Chicago, IL. The interdisciplinary design team, made up of architects and engineers, will apply building science principles to achieve a solution that is high-performance, cost-efficient, structurally sound, and aesthetically pleasing. The design will meet both the requirements of the DOE Zero Energy Ready Home as well as the International Energy Conservation Code (IECC) 2012.

Relevance of Project to the Goals of the Competition



By designing the Net-Zero IIT townhouse with this interdisciplinary team, students will uniquely gain the applied knowledge to develop into the next generation of residential design professionals with building science expertise. By integrating the Race to Zero design competition into coursework, applied building science education will be enhanced at IIT.

Design Strategy and Key Points

In order to achieve the goals of designing an affordable, energy efficient, and healthy home, the following design strategies will be utilized:

o Integrated Design: An interdisciplinary team of architects and engineers will work in tandem to develop the form, function, and aesthetics of the home.

o Energy conservation and optimization: The team will utilize building energy simulation and optimization software (BEopt with EnergyPlus) to perform energy modeling in the early stages of the design phase. The same tools will also be used to optimize for cost Net-Zero IIT townhouse effective combinations of energy efficiency construction features and on-site renewable energy supply systems.

o Building enclosure: The building enclosure will follow Passive House design standards and will be designed using thermal-bridging free construction.

Project Data

- Location: Chicago, IL
- ASHRAE climate zone 5
- Area :2,280 sq. ft/unit
- 4 bedrooms, 2 bathrooms, and 2 stories per unit
- HERS score: 37 w/o PV; -3 w/ PV
- Estimated monthly energy cost: $58/unit w/o PV; $4/unit w/ PV

Technical Specifications

- Wall Insulation = R-56 (Cavity insulation + continuous insulation) o o Foundation Insulation = R–50
- Roof Insulation = R–63
- Window Performance = U–0.17 SHGC: 0.27
- HVAC specifications = SEER 22 and HSPF 10.0

2 | Design Goals

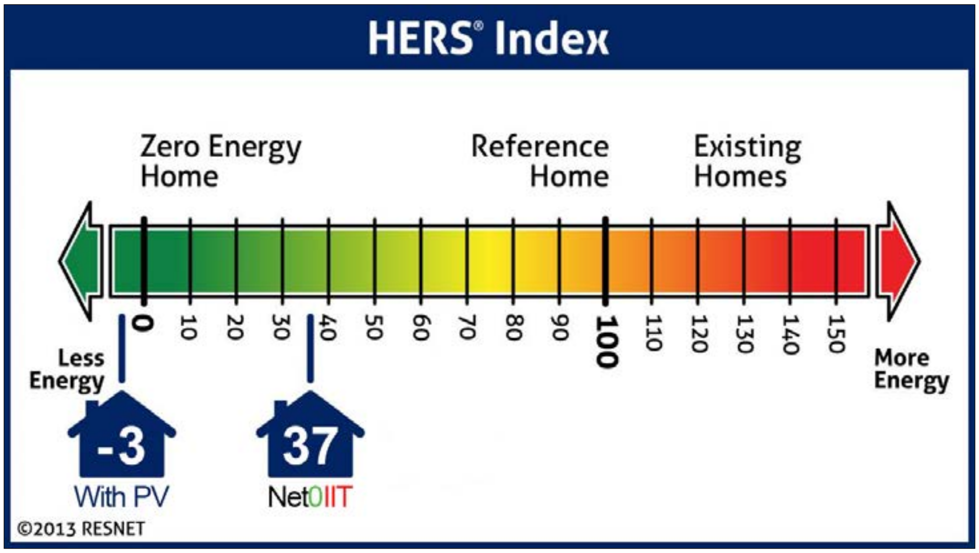
The site was chosen at the intersection of South Drexel Avenue and 63rd Street in Chicago, IL, intersecting Hyde Park and the Woodlawn neighborho8od. Once, the site for the 1893 World's Fair and now located near the University of Chicago, the area became home to people from very diverse cultures and backgrounds in early 21st century. The neighborhoods then went through painful history of segregation and poverty that created a stark contrast between Hyde Park and its surrounding neighborhoods. While Hyde Park is one of the wealthiest neighborhoods in Chicago that continues to develop, nearby Woodlawn maintains on of the lowest per capita incomes in the City of Chicago, lacks infrastructures, and contains many abandoned lots and empty houses.

Our goal was to provide affordable housings on the northern portion of Woodlawn for families and students of the University of Chicago. The area has the highest chance to become a host for the new Obama Presidential Library, which would bring new infrastructures and attention to the area. By providing affordable, net-zero energy housing, we can increase opportunities for people to stay in the neighborhood as it redevelops. Further, having residents of the Woodlawn community living side by side with students from the University of Chicago can create more interactions between Woodlawn and Hyde Park, helping to reimagine a cultural melting pot and create brighter future for the neighborhood.

The design intention was to create a simple architecture that maximizes spaces for occupants while keeping the units cost effective, energy efficient, and durable to withstand Chicago's harsh weather, all while meeting the net-zero energy standard.

Constraints of the narrow lot size presented a challenge for meeting the net-zero energy requirements while providing sufficient space for occupants on a relatively small footprint. Each unit consists of a core area and two living spaces either side that creates three distinct living spaces. The core on the first floor provides the kitchen, bathroom, utility room, and storage spaces, while the second floor core provides two bathrooms and a laundry room. The living rooms are located on the west side of the units, while the dining rooms are located on the east side, both on the first floor. Two bedrooms occupy each sides of the second floor, separating the rooms as much as possible for privacy. The plan is nearly symmetrical along the north-south axis, which enables the units to be divided up for large families or for 4-5 students to live comfortably.

The empty space spanning the first and second floors of the east side of each unit provides a space for stack-driven natural ventilation flow in appropriate seasons facing the first core along the north-south axis not only creates more privacy from the community living spaces, but it also provides clean finishes facing towards the living spaces for occupants to decorate. The entire building was designed with a flat roof to maximize the area for energy production by the photovoltaic system.



Home Energy Rating System(HERS) Index is the industry standard for measuring energy efficiency of a home. It was calculated using the software REM/Rate. A rating of 100 is the standard for new homes. We were able to get a HERS score of 37 without PV. It signifies that our home was 63% more efficient than a standard new home of the same shape and size. With the installation of PV systems, the HERS score lowered down to -3.

3 | Envelope Durability

Building enclosure design plays a critical role in the energy and durability of the home. If the enclosure is not designed properly, the enclosure potentially causes moisture problems, high utility bills, and structural safety issues. At the same time, the envelope itself should be feasible to construct by trades. Thus, our team first used BEopt with Energy Plus to select cost-optimal envelope construction and then conducted WUFI simulations to identify whether or not there were potential moisture issues within the chosen enclosure assembly in our climate. We then used detail drawings from the Building Science Corporation, Green Building Advisor, and other home building references to ensure the wall's constructability.

The optimized enclosure assembly consists of: (1) a double wood stud wall with R-45 fiberglass batts installed 24" on center (effective R-value of approximately 35 h-ft2-°F/Btu), with 3 inches of XPS wall sheating (R-15) to minimize thermal bridging; (2) roofing insulating comprising R-38 fiberglass batts installed in 2x10 wood studs with R-25 exterior rigid XPS insulation (effective assembly R-value of approximately 61h-ft2-°F/Btu); (3) low-emissivity triple-glazed argon-filled windows with insulated frames (U-0.17 Btu/h-ft2-°F and SHGC = 0.27); and (4) R-40 insulation below the slab with R-10 perimeter gap insulation placed vertically between the edge of the slab and the foundation wall. Full optimized enclosure details are shown in Table 1.

Table 1. Optimized envelope details from the BEopt analysis

Simulation subgroup	Option	Selected option from BEopt simulations	Note
Envelope	Double wood stud	R-45 Fiberglass, Gr-1, Centered. 24 in O.C.	Assembly R-34.7 (IP)
	Wall sheathing	XPS	R-15 (IP)
	Exterior finish	Vinyl	Light color, Solar absorptivity: 0.3, Emissivity: 0.9
	Finished roof	R-38 Fiberglass Batt, Gr-1, 2x10, with R-25 XPS exterior insulation	Assembly R-61.3 (IP)
	Roof material	Asphalt shingles, White color	Absorptivity: 0.75, Emissivity: 0.91
	Slab	Whole slab XPS	R-40, R-10 *Gap XPS
	Windows	Low-E, Triple, Insulated, Argon	U-0.17 (IP), SHGC: 0.27
	Doors	Steel doors, Swinging operation	U-0.2 (IP)

* Gap – placed vertically between the edge of the slab and the foundation wall

[1] http://www.greenbuildingadvisor.com/articles/dept/musings/exterior-rigid-foam-double-stud-walls-no-no

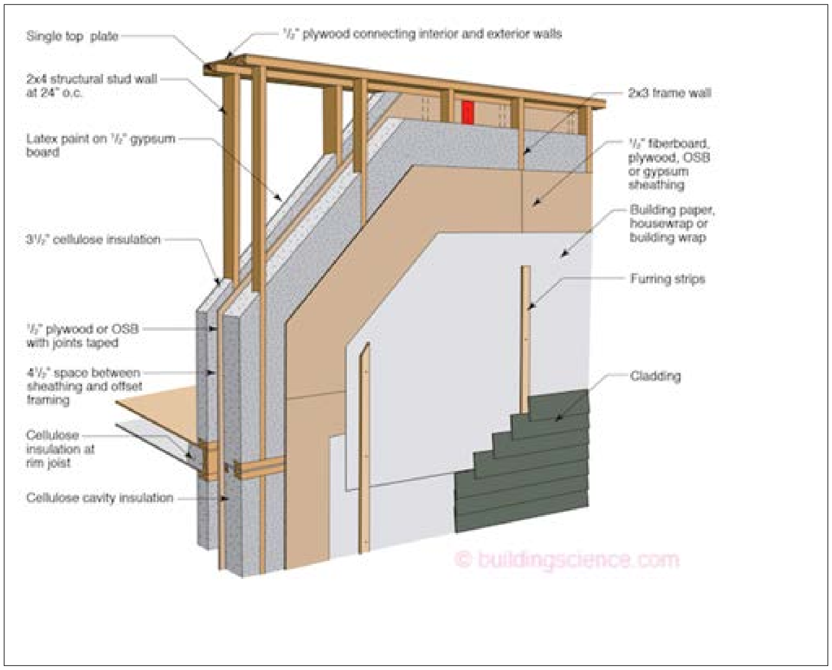


Figure 1. Example double stud wall enclosure detail from Building Science Corporation. Note that the 1/2″ OSB sheathing between the two double stud cavity layers is replaced by 3.5″ of rigid XPS insulation in our detail.

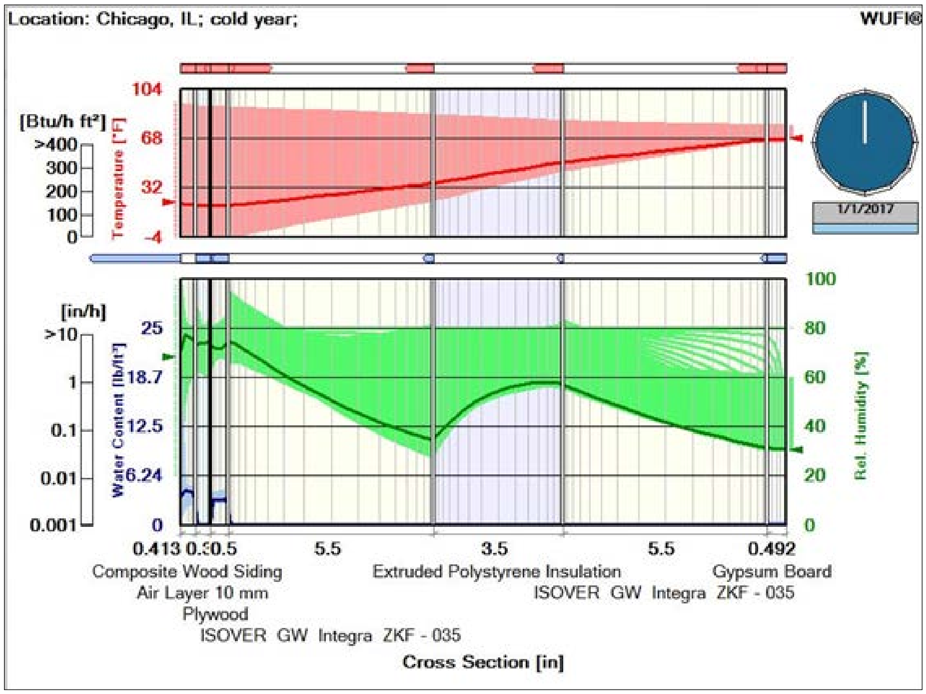
Thewhole-assembly effective R-value for this wall was calculated to be R-52 h-ft2-°F/Btu.

Layer Material	Conductivity (K)	Thickness (L)	Conductance (U)	Resistance (R)
	Btu in/ ºFhft2	in	Btu/ºFhft2	ºFhft2/Btu
Interior film			1.41	0.71
Gypsum board		0.5	2.38	0.42
1.5 inch woodstud and 24 inch fibreglass		5.5	0.06	16.13
XPS insulation	0.17	3.5	0.05	20.25
1.5 inch woodstud and 24 inch fibreglass		5.5	0.06	16.13
Plywood	0.58	0.5	1.16	0.86
Building paper			0	0
Air Layer		0.394	1.25	0.8
Vinyl	0.83	0.5	1.67	0.6
Exterior film			6.07	0.16
			Total thermal resistance	56

[2]http://www.greenbuildingadvisor.com/articles/dept/building-science/lstiburek-s-ideal-double-stud-wall-design

Hygrothermal Analysis using WUFI

Next, hygrothermalanalysis was conducted using WUFI. Simulation results are shown below. No condensation issues were predicted between any of the wall layers.



4 | Indoor Air Quality (IAQ) and Appliances

Project Summary

The team has carefully chosen several elements to accomplish the requirements of the EPA Indoor airPLUS program in order to provide excellent indoor air quality (IAQ) in the townhouse units.

Ventilation Requirements

First, minimum whole-house ventilation requirements were calculated according to ASHRAE Standard 62.2 (2010): Ventilation and Acceptable Indoor Air Quality, as follows:
ASHRAE 62.2-2010 -> Q = 0.01 cfm/ft2 * 2380 ft2 + 7.5 cfm/br * (4 + 1) br = 61.3 cfm

Additionally, ASHRAE Standard 62.2 also requires exhaust fans to be installed in the three bathrooms, kitchen, and laundry areas for each unit. The City of Chicago building code also has requirements for exhaust ventilation. Both are shown in the table below:

Exhaust ventilation rates (cfm)		
ROOM	ASHRAE 62.1	Chicago Building Code
Kitchen	100	173
Bathroom 1st floor	50	45
Bathrooms 2nd floor (each one)	50	93
Residential Dryers	27	0

Based on these combined requirements, we have designed the ventilation system to have 65 cfm of continuous whole-house exhaust, as well as local exhaust fans capable of achieving at least 175 cfm in the kitchen, 50 cfm in the 1st floor bathroom, 100 cfm in each of the 2nd floor bathrooms, and 30 cfm in the laundry room.

Equipment Selection

To efficiently deliver the required whole-house ventilation flow rate, we have chosen to use a wthole-house energy recovery ventilator (ERV) operating continuously in each unit.
Since we are using a mini-split heat pump for heating and cooling, we selected the Zehnder ComfoAir 160 ERV stand-alone ventilation unit. The unit allows us to achieve up to 92 cfm of fresh air continuously, and also can be combined with a MERV 13 particle filter to avoid the introduction of undesirable outdoor particulate matter and allergens.
The system will be also combined with a CO_2 occupancy sensor in order to supply outdoor air only when it is necessary.

Zehnder ComfoAir 160 ERV

Design and Materials

Providing natural ventilation:

In the townhouse design, each unit is provided of operable windows, so the occupants have the opportunity to increase the amount of fresh air received by opening them.

Avoiding and eliminating pollutants at the source:

The team has decided to forego attached garages to prevent garage-source contaminant entry. We have also opted for all-electric appliances to prevent indoor NOx and particle emission sources from gas appliances.
The team has chosen a variable speed range hood with high capture efficiency, explained in detail in section "4.2 appliances", located above the electric range, which will be wider than the cooking surface to eliminate cooking pollutant emissions. It will operate at a minimum capacity of 175 cfm to remove these potential pollutants directly at the source.
Each unit will be continually ventilated by the whole-house mechanical system, running at least at the required continuous ventilation rate of 65 cfm. We have also placed exhaust fans in all bathrooms and laundry room that will be directly venting the air to the outdoors through the energy recovery ventilation ducts.
The exhaust fan chosen for the second floor bathrooms is Panasonic WhisperCeiling FV-11VQ5. In the first floor bathroom and laundry room, we will use the Panasonic WhisperCeiling FV-05VQ5 because it features condensation control and a smart exhaust function based on humidity and occupancy.

Radon strategies:

Chicago is located in zone 2 of the EPA radon map, being at moderate potential risk for radon exposure. The townhouse is intended to prevent radon exposure to the minimum, by using mat foundation and discarding a possible basement. The concrete layer on the foundation will be also sealed with a layer of RadonSeal Deep-Penetrating Concrete Sealer.

Materials and finishes selection:

NetZero-IIT has opted to use highly insulated enclosure assemblies, which helps to minimize interior moisture condensation problems that could lead to biological growth that would affect IAQ (these details are described in another chapter). Furthermore, we have chosen the Natura collection for finishes, a non-emitting VOC paint from Benjamin Moore, to cover all the interior walls and ceilings.
In each unit we will use hardwood flooring (except for the bathrooms and kitchens where we will use ceramic tile), choosing the oak-natural finish from Armstrong brand, which meets the CARB requirements for IAQ and satisfies our goal of having low formaldehyde emissions. Last, we have specified that all furniture in the units must also meet the CARB requirements in order to accomplish with the EPA Indoor airPLUS requirements.

Appliances

The appliances chosen are listed on the table below. We have chosen gathered energy star rated units and balanced the cost considerations with the financial analysis team.

Appliances	Specifications	Baseline	Price ($)
Kitchen			
Range hood	36" Convertible Wall-Mount 400-CFM Glass Canopy Hood (UXW6536BSS) - CFM 175-400	EnergyStar	450
Cooking range	Whirlpool 4.8 cu. ft. Electric Range w/ Self-Cleaning Oven (WFC340S0AW) - Stainless steel - 40 amp -220/240V		390
Dishwasher	Whirlpool Dishwasher with AnyWare Plus Silverware Basket (WDF520PADM) - 260 KWh/year - 4.5 gal/cycle	EnergyStar	220
Refrigerator	Frigidaire, 16 cu. ft. Top Freezer Refrigerator in Stainless Steel (FFHT1621QS) - 348 KWh/year	EnergyStar	550
		Total	1610
Laundry			
Washer	Whirlpool, Duet 4.2 cu. ft. High-Efficiency Front Load Washer in White (WF-W72HEDW) 109 KWh/year	EnergyStar	425
Dryer	Whirlpool, Duet 7.3 cu. ft. High-Efficiency Electric Dryer in White (WED-72HEDW) 150 KWh/year	EnergyStar	425
		Total	850
		Total	2460

5 | Space Conditioning & Ventilation

Systems approach & performance objectives

The goals of the mechanical design were to provide:
- Proper sizing and appropriate mechanical system selection for ASHRAE climate zone 5
- Energy-star equipment at a reasonable costs
- Minimized ductwork length
- Provide exceptional thermal comfort

Heating and cooling loads calculations

Heating and cooling load calculations were performed using the auto-size tool in EnergyPlus with default inputs for lighting, equipment, appliance, and occupant loads. Once BEopt created EnergyPlus input files (i.e., IDF files), we manually extracted the auto-sized systems from the files. Calculated heating and cooling loads for each unit are shown below.

Table 2. Heating and cooling loads by each unit

	Unit Number				
	1	2	3	4	Total
Cooling Load (tons)	1	1	1	2	5
Heating Load (kBtu/hr)	27	18	18	35	98

Selecting mechanical systems

During the initial energy analysis, our team performed BEopt simulations with various mechanical options (e.g., various types and efficiencies of central air conditioning units, boilers, furnaces, and heat pumps) to find cost-optimal efficient solutions. The energy analysis identified that an air-source mini-split heat pump with supplemental electric baseboard heating was the most cost-effective way to efficiently heat and cool the townhouse units saving up to 13 MMBtu/year compared to the other options.

Mini-split heat pump systems have other advantages as well, including:

1. Heating and cooling can be provided zone by zone
2. The equipment is available in smaller sizes, better matching the calculated heating and cooling loads
3. Ductwork is not required for mini-split heat pumps, which means no energy losses through duct heat transfer and less time/effort required for duct design and installation
4. Very high efficiencies (e.g. SEER and HSPF)
5. Quiet operation
6. Controlled with a remote control
7. Relatively easy maintenance (i.e., to keep the filters and coils clean)

Specifying the mini-split heat pump system

Our team chose to specify a Toshiba and an Infiniti residential ductless multi-zone heat pump system (RAS-EAV and 38 GJQ systems). The Infiniti system has multi-zone indoor combinations for up to 9 zones. However, as the number of zones increases, the efficiency decreases. For example, the efficiency of the 2-zone model is up to SEER 22 and HSPF 9.0 but the 9-zone model achieves only 16 SEER and HSPF 8.2. In order to maintain high efficiency, our team decided to divide the town house into one zone for the first floor and five zones for the second floor, which enabled SEER 23 and HSPF 10.0 for the first floor and SEER 21 and HSPF 8.2 for the second floor.

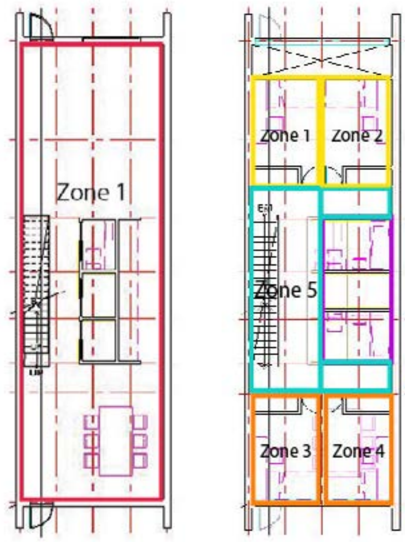


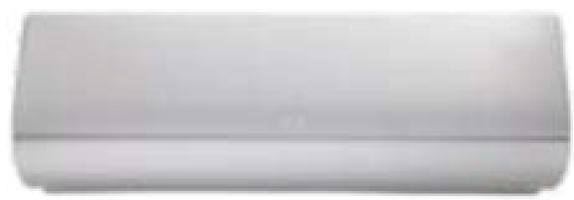
Figure 2. Left: First floor zoning, Right: Second floor zoning

For the first floor, we decided to install outdoor model RAS-12EAV-UL with one indoor high wall unit for air distribution. Similarly, for the second floor, we selected outdoor model 38GJQG36-3 with one cassette and four indoor high wall units for air distribution. The equipment is summarized below.

Table3. Upper: RAS-12EAV-UL Lower: 38GJQG36-3

	Outdoor model	RAS-12EAV-UL
	Max number of zones	1
	Cooling rated capacity (tons)	1
	Cooling cap. Range Min ~ Max (tons)	0.2 ~ 1.2
	SEER	23
	Heating rated Capacity (kBtu/h)	14
	Heating cap. Range Min ~ Max (KBtu/h)	3 ~ 19
	HSPF	10.0
	Airflow (cfm), (Cooling/Heating)	406/438

Outdoor model	38GJQG36-3
Max number of zones	5
Cooling rated capacity (tons)	2.8
Cooling cap. Range Min ~ Max (tons)	0.7 ~ 3.0
SEER	21
Heating rated Capacity (kBtu/h)	42.5
Heating cap. Range Min ~ Max (kBtu/h)	8.8 - 44.3
HSPF	10.2
Airflow (cfm)	4,531



Indoor Cassette	Indoor High Wall

Figure 3. Indoor equipment

We should note that when the BEopt simulations were conducted, we modeled a mini-split heat pump with electrical baseboard heating as back-up heating equipment. However, we decided not to install electrical baseboard because the chosen equipment cooling capacity ranged from 1 ton to 4 tons and heating capacity ranged from 12 kBtu/hr to 63 kBtu/hr, which is in the range of the calculated heating and cooling loads in Table 1. Thus, it was not necessary to install back-up heating equipment in the townhouse units.

Mechanical Ventilation

In order to provide adequate ventilation rates in the airtight townhouse units with minimal energy impacts, we decided to install a balanced ventilation system with an energy- recovery ventilator (ERV). Required whole-house were calculated using ASHRAE 62.2 – 2010: 61 cfm per townhouse/unit. The selected ERV model is further detailed in the IAQ section.

6 | Energy Analysis

The overall strategy for improving energy sustainability in the townhouse units was to first reduce building energy use by selecting cost-effective building materials to reduce heating and cooling loads, then to select high-efficiency equipment to reduce HVAC and appliance energy use, and then to introduce an on-site solar array to achieve net zero energy use on an annual basis. Our team utilized BEopt with EnergyPlus to first identify cost-optimal enclosure requirements and then again to identify cost-optimal requirements for appliances and equipment including, lighting, HVAC systems, and water heating. After the simulations were conducted, we used PVWatts to size a roof-mounted solar PV array and predict the amount of electricity that would be produced to achieve net zero energy use. Last, we also used REM/Rate calculate a HERS Index for the townhouse both with and without the on-site renewable energy system.

Building Energy Optimization

The sequence of the BEopt simulations is shown below:

1. Building enclosure and openings (windows and doors)
2. HVAC systems and water heating
3. Appliances and lighting
4. Photovoltaic (PV) systems

The orientation of the townhouse and its surrounding neighbors were held constant based on the characteristics of the site limitations. The following assumptions were applied to each building simulation run. The heating set point was 70 ºF and the cooling set point was 72 ºF. Envelope air tightness was designed to meet Passive House standards at 0.5 ACH 50. Miscellaneous plug loads for the town house were set as BEopt defaults of 616 kWh/unit/yr. According to the BEopt simulations, the following options were selected as the cost-optimal combinations among the selected range of options.

Table 4. Optimized options from BEopt analysis

Simulation subgroup	Option	Selected option from BEopt simulations	Note
Envelope	Double wood stud	R-45 Fiberglass, Gr-1, Centered. 24 in O.C.	Assembly R- 34.7 (IP)
	Wall sheathing	XPS	R-15 (IP)
	Exterior finish	Vinyl	Light color, Solar absorptivity: 0.3, Emissivity: 0.9
	Finished roof	R-38 Fiberglass Batt, Gr-1, 2x10, with R-25 XPS exterior insulation	Assembly R-61.3 (IP)
	Roof material	Asphalt shingles, White color	Absorptivity: 0.75, Emissivity: 0.91
	Slab	Whole slab XPS	R-40 (IP) perimeter gap*, R-10 (IP) below slab
	Windows	Low-E, Triple, Insulated, Argon	U-0.17 (IP), SHGC: 0.27
	Doors	Steel doors, Swinging operation	U-0.2 (IP)
HVAC	Heating and Cooling	Mini-split heat pump	SEER 27, 11.5 HSPF SEER 22, 10.8 HSPF**
	Supply Heating	Electric baseboard	100% Efficiency
	Mechanical Ventilation	Exhaust, 50% of 2010 ASHRAE 62.2	28.2 cfm/unit, 8.5 W/unit
	Ceiling Fan	None	n/a
Water heating	Water heater	Heat pump water heater, 80 gal	Energy Factor: 2.3
Appliances	Refrigerator	Top freezer	Energy Factor: 19.9
	Cooking Range	Electric, 80% Usage	Cooktop energy factor: 0.74
	Dishwasher	80% Usage	290 kWh
	Clothes washer	EnergyStar, cold only	123 kWh
	Clothes dryer	Electric, 80% Usage	Energy Factor: 3.1 lb/kWh)
Lighting	Lighting Fixtures	100% LED	Annual Electricity use: 1362 kWh/unit/yr
Miscellaneous	Carpet	-	0% Carpet
	Overhangs	-	None
	Eaves	-	None

* Gap – placed vertically between the edge of the slab and the foundation wall

** In the subsequent mechanical systems design, no multi-zone mini-split heat pump systems achieving SEER 27 and HSPF 11.5 were available on the market. Instead, SEER 23/HSPF 10.0 systems were installed on the first floors and SEER 21/HSPF 10.2 systems were installed on the second floors. However, it was impossible to select two different equipment efficiencies in one unit in BEopt. Thus, the mechanical simulation was proceeded with the average SEER value between the equipment on first floor and the equipment on the second floor, which is SEER 22/HSPF 10.8.

Solar PV Installation

Once the building energy demand analysis was finalized, we then used PVWatts to design a roof-mounted PV system. We chose a flat roof design because initial sloped roof designs would not provide an area enough large for a PV array to achieve net zero energy status. The entire roof was considered to be covered by PV panels, albeit with a small distance provided to walk along the perimeter, which provided a total area of 404 ft2. We assumed that the solar panels were installed on a fixed array with "premium" solar panels from SolarCity, with a module efficiency of 22%. Thus we obtained a DC system size of 82kW. System losses were assumed to be 14% with a tilt angle of 0°. The DC to AC size ration was assumed to be 1.1 with an inverter efficiency of 96%.

Result

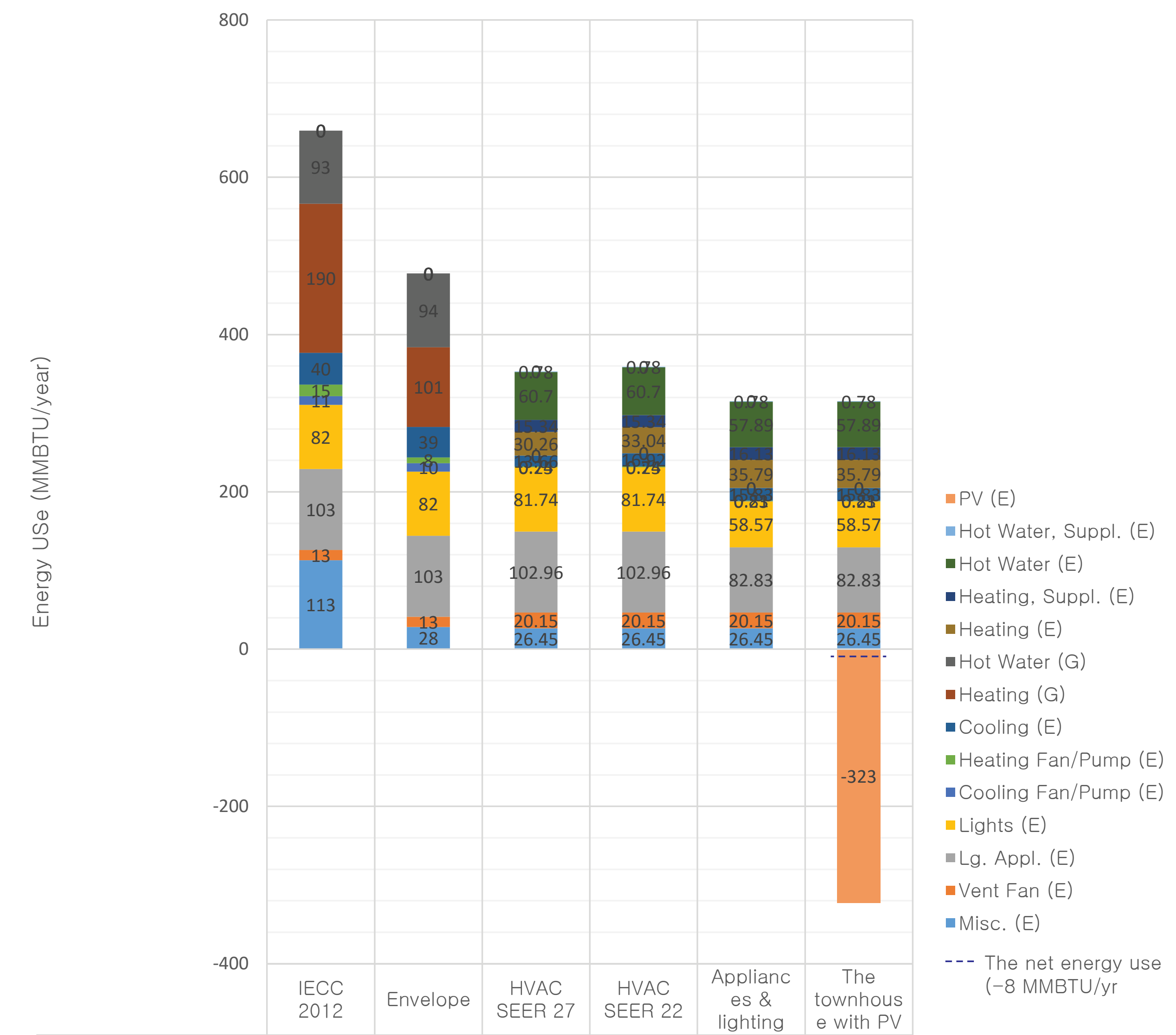
Figure 1 shows the predicted annual energy end uses across all 4 townhouse units under several modeled scenarios, including:

1. Baseline IECC2012
2. After optimized envelope retrofits only
3. After optimized envelope + HVAC components (optimal)
4. After optimized envelope + HVAC components (realistic, with lower SEER)
5. After optimized envelope + HVAC components + lighting + appliances
6. The low-load townhome (scenario 5) with a roof-top PV system

These same annual end uses are also summarized on a whole-house basis in Table2. The combination of the envelope, HVAC, lighting, and appliances improvements as predicted to reduce energy use in the townhouse

Table 5. Total energy use comparison

	IECC 2012	Envelope	HVAC SEER 27	HVAC SEER 22	Appliances & lighting	The townhouse with PV
Total (MMBTU/yr)	659	478	353	359	315	-8



	IECC 2012	Envelope	HVAC SEER 27	HVAC SEER 22	Appliances & lighting	The townhouse with PV
PV (E)	0	0	0	0	0	−323
Hot Water, Suppl. (E)	0	0	0.78	0.78	0.78	0.78
Hot Water (E)	0	0	60.7	60.7	57.89	57.89
Heating, Suppl. (E)	0	0	15.34	15.34	16.13	16.13
Heating (E)	0	0	30.26	33.04	35.79	35.79
Hot Water (G)	93	94	0	0	0	0
Heating (G)	190	101	0	0	0	0
Cooling (E)	40	39	13.66	16.92	15.83	15.83
Heating Fan/Pump (E)	15	8	0.74	0.74	0.81	0.81
Cooling Fan/Pump (E)	11	10	0.25	0.25	0.23	0.23
Lights (E)	82	82	81.74	81.74	58.57	58.57
Lg. Appl. (E)	103	103	102.96	102.96	82.83	82.83
Vent Fan (E)	13	13	20.15	20.15	20.15	20.15
Misc. (E)	113	28	26.45	26.45	26.45	26.45

Figure 4. Energy use comparison for several scenarios, culminating with the low-load home with high efficiency equipment, appliances, and lighting and on-site PV array

7 | Financial Analysis

Summary

The objective of this financial analysis is to estimate the end price of an individual unit in the net zero townhome and ensure that it remains affordable and economically feasible to wide segments of the population. We have based our analysis assuming the average median family income for the Chicago area where the home will be constructed [1]. This section describes the economic costs of each of our net zero units, including construction costs, rebates and incentives, sales price estimates, and a homeowner cash flow analysis. We rely on several assumptions listed below:

1. The cost of most components was sourced from RSMeans database.
2. The sale price was estimated based on a percentage value of total construction cost obtained from the national construction cost survey data generated by the NAHB [2].
3. The national average costs were obtained from NAHB: Cost of Constructing a Single-family Home in 2015 [2].
4. The principle for the loan is assumed to be 70% of the sale price of the house, so the down-payment for the loan is 30% of the sales price.
5. The rate of inflation is based on the historic average rate of inflation of USA from 2005- 2015, which released by the Bureau of Labor (2.1%) [3].
6. For the Chicago housing market, the median family income is approximately $62,000.

Construction cost estimate

The construction cost of our units is broken down on a component basis. The cost for each item was estimated by summing the price per unit for labor, materials, and equipment. The location adjustment factor is also included in calculation. In the costs of site work, the permit fee was calculated based data provided by the City of Chicago (Table 1). Other site work costs were estimated based on average construction cost data obtained from the 2015 national survey published by NAHB.

Table 6. Costs of site work breakdown

Construction Cost Breakdown		Team Default Estimate for Share of Construction Value	Team Estimate Share of Construction Value	Team Estimate Per sq.ft.
Site Work (sum of A to E)		$13,094	$12,865.08	$5.64
A	Building Permit Fees	$2,930	$2,701	$1.18
B	Impact Fee	$1,417	$1,417	$0.62
C	Water & Sewer Fees Inspections	$3,410	$3,410	$1.50
D	Architecture, Engineering	$3,729	$0	$0
E	Other	$1,607	$1,607	$0.70

The total construction cost for each unit is estimated to be $256,646 without any energy efficiency or renewable energy incentives. The total construction cost breakdown is shown in Figure 1. The largest cost components are interior finishes, followed by framing. The total construction cost is higher than the average single-family home in the U.S., but the long-term operational costs are lower because the home is designed to meet its net zero energy goal.

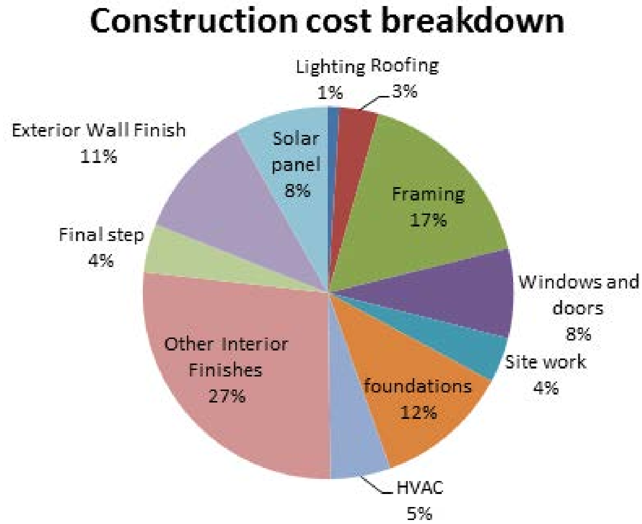


Figure 5. Total construction cost breakdown

There is also a number of federal and state energy efficiency and renewable energy incentives that can be applied to further reduce the total construction cost. These are listed in the Database of State Incentives for Renewables & Efficiency (DSIRE), and described in more detail below. For example, the federal government offers a rebate that can cover 30% of total solar panel costs [4]. The state of Illinois also offers a rebate of 25% of the total solar panel costs [5]. Based on market prices, we estimated the original total cost of the solar panel array to be $19,047 [6], while the final price of the array after incentives is shown in Table 2.

Table 7. Incentives for the solar panel array

Original price	$19047
Federal rebate	$5714
State rebate	$4762
Final price	$8571

The state of Illinois also offers $4650 in rebates for single-family homes that use high efficiency windows and LED lightings [7]. In Illinois, Nicor Gas also offers residential energy efficiency rebates of $1000 to help cover the cost of increased building insulation and higher efficiency appliances [8]. Details of the Nicor Gas rebates are listed in Table 3. Finally, the federal government also offers $500 in tax credits each year for homeowners that participate in their residential energy efficiency tax credits program [9].

Table 8. Nicor Gas - Residential Energy Efficiency Rebates break down

High Efficiency Furnace	$250
Air Sealing	$400
Duct sealing	$300
Wall Insulation	$400
Total	$1350

After applying each of these incentives, the total construction was reduced by approximately 8% to $235,611.

Sale price estimate

Next, we calculated the sale price based on our construction cost estimates and average NAHB data, shown in Table 4. The default estimated sale price is $347,863, while the revised estimated sale price is $322,148 using more appropriate local data. A major reason for these adjustments is that the finished lot-to-home price in the Midwest tends to be in the 15% to 20% range, while the average ratio is 30% in the United States [10]. After applying incentives and rebates, the adjusted estimated sale price of our house is around $50,000 lower than the average price of similarly sized homes in the United States.

Table 9. The sale price break down

NAHB Sales Price Breakdown	Team Default Estimate	Team Adjusted Estimate
Finished Lot Cost (including financing costs)	$71,197	$38,488
Overhead and General Expenses	$16,569	$16,569
Marketing Cost	$4,071	$4,071
Sales Commission	$13,602	$13,602
Profit	$35,599	$35,599
Total Sales Price	$376,538	$322,148

Financial analysis

We make several assumptions to perform the homeowner cash flow financial analysis. We assumed that the down payment is 30% of the total sale price; the utility costs are from the City of Chicago data; and the homeowner's income is the median family income in Chicago in 2015 ($61,641). Table 5 shows the loan break down. Table 6 shows estimated monthly utility costs. Table 7 shows the estimated debt-to-income ratio, which is able to achieve 38%.

Table 10. Loan break down

Annual Interest Rate	3.5%
Years	30 years
Payments per Year	12
Number of Payments	360
Down payment	$104,359
Principle Amount	$243,504
Monthly Payment	$(1,093)

Table 11. Monthly utility cost

Utility cost Breakdown	Average in Chicago	Team Estimate
Electricity	$111	$0
Natural Gas	$31	$0
Water	$18	$22
Other	$0	$0
Total	$160	$22

Table 12. Debt to income ratio

Monthly Household Debt	$30
Operations and Maintenance Costs	$196
Monthly Utility Costs	$21
Property Tax	$541
Insurance	$65
Mortgage Payment	$1,093
Calculated Debt to Income Ratio	38%

References

[1] www.deptofnumbers.com/income/illinois/chicago
[2] http://eyeonhousing.org/2015/12/top-posts-of-2015-cost-of-constructing-a-single-family-home-in-2015/
[3] http://data.bls.gov/timeseries/CUUR0000SA0L1E?output_view=pct_12mths
[4] http://programs.dsireusa.org/system/program/detail/1235
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[6] http://www.ebay.com/itm/BrandNew-10000W-10KW-24V-Solar-Panels-Home-Power-Generator-Free-Sea-Shipping-/131233013406?_trksid=p2141725.m3641.l6368
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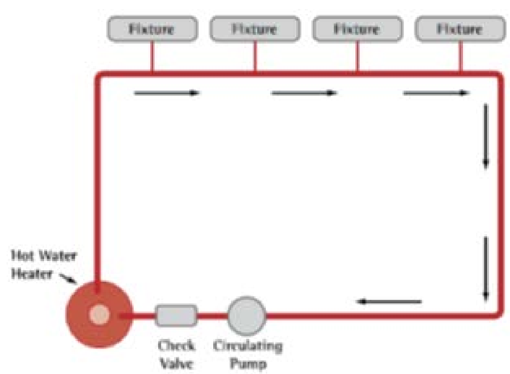
8 | Domestic Hot Water AND Lighting

Domestic hot water

In order to reduce the energy required to heat and supply domestic hot water throughout the units, we have selected efficient water fixtures, high efficiency water heaters, and efficient hot water delivery systems. We have specified EPA WaterSense labeled water fixtures throughout the units, which use less water than conventional water fixtures. These include the Kitchen Faucet (2.2 gpm), Bathroom Lavatory Faucet (1.5 gpm), and Showerhead (2.0 gpm). The selected fixtures are shown below.

Fixtures	Specifications	Certification	GPM	Price ($)
Kitchen Faucet	Kraus KPF-1630SS Nola Single Lever Pull-down Kitchen Faucet Stainless Steel Finish	WaterSense	2.2	180
Lavatory Faucet	Delta B501LF Foundations Single Handle Lavatory Faucet Less Pop-Up, Chrome	WaterSense	1.5	55
Diswasher	Delta Faucet 75409 Universal Showering Components, Five Setting H2OKinetic Hand Shower, Chrome	WaterSense	2.0	35

Rheem Water Heater



Demand-Initiated Recirculation System

We used a Demand-Initiated recirculation system to supply hot water throughout each unit. This system consists of a continuous hot water supply loop that recirculates water throughout the home. A circulation pump draws hot water through the recirculation loop and returns it to the water heater. This system is efficient because it reduces the wait time for hot water and because water is returned back to the heater. Additionally, a high efficiency Rheem electric water heater with an energy factor of 0.95 and 50 gallon tank was selected for each unit.

Hot water Delivery System Calculations

Hot water calculations were conducted using the EPA WaterSense flow rates. In order to reduce the energy required to recirculate the water through pumps, we located fixtures such a way that smaller recirculation loops are used. Calculations are shown below.
With our design, the highest flow fixture has a volume of 0.230 gallons (which is under the WaterSense total hot water volume limit of 0.5 gallons) and has a wait time of 6.9 seconds (which is below ASPE acceptable performance of 10 seconds). To reach these numbers our water fixtures were specifically designed to be in close proximity to each other, providing us with a smaller recirculation loop (see pipe segments plan).

Fixture	Pipe segment	Pipe diam. [in]	Water capacity [oz/ft]	Pipe lenght [ft]	Water volume [gal]
1st floor Kitchen sink	Drop from loop	1/2	1.89	1.75	0.026
	1	1/2	1.89	1.06	0.016
Total hot Water Volume [gal]					0.041
Hot Water Wait Time [sec]					1.132
1st floor Washing Machine	Drop from loop	1/2	1.89	0.93	0.014
	2	1/2	1.89	0.38	0.006
Total hot Water Volume [gal]					0.019
1st floor Lavatory sink	Drop from loop	1/2	1.89	7.1	0.105
	3	1/2	1.89	0.38	0.006
Total hot Water Volume [gal]					0.110
Hot Water Wait Time [sec]					4.418
1st floor Dish-washer	Drop from loop	1/2	1.89	26	0.384
	4	1/2	1.89	1.06	0.016
Total hot Water Volume [gal]					0.400
2nd floor Lavato-ry sink	Drop from loop	1/2	1.89	4.78	0.071
	5	1/2	1.89	2.56	0.038
Total hot Water Volume [gal]					0.108
Hot Water Wait Time [sec]					4.335
2nd floor Shower	Drop from loop	1/2	1.89	13.38	0.198
	6	1/2	1.89	2.2	0.032
Total hot Water Volume [gal]					0.230
Hot Water Wait Time [sec]					6.901
2nd floor Lavato-ry sink	Drop from loop	1/2	1.89	5.78	0.085
	7	1/2	1.89	1.57	0.023
Total hot Water Volume [gal]					0.109
Hot Water Wait Time [sec]					4.341
2nd floor Shower	Drop from loop	1/2	1.89	5.78	0.085
	8	1/2	1.89	2.2	0.032
Total hot Water Volume [gal]					0.118
Hot Water Wait Time [sec]					3.535

1. Assumes a kitchen faucet flow rate of 2.2 gpm, as required in the specification.
2. Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.
3. Assumes a showerhead flow rate of 2.0 gpm (maximum flow rate for WaterSense labeled showerheads), as required in the specification.

Lighting

Our lighting design goal was to meet Energy Star requirements and reduce lighting energy requirements. The lighting requirements for residential units were obtained from IESNA Lighting Handbook, 8th edition. Philips InstantliftT8 linear LED lamps and Cree 60W equivalent soft white A19 bulbs were chosen. They were considered after confirming that they satisfy Energy Star requirements.

Table 1. Energy Star Requirement

	Energy Star Requirement	Cree 60W equivalent A19 LED bulb	T8 Linear LED
Minimum Color Rendering Index	80	80	82
Minimum Luminous Efficacy	55lm/W	84.2 lm/W	103 lm/W
Minimum Lifetime	25,000 hrs	25,000 hrs	40,000 hrs
Minimum Light Output	800 lm	800 lm	1500 lm

The number of lamps required for each room was calculated using the Illuminance required for each room and Lamp Light Output. Average daily usage of lamps were estimated for each room and net energy consumption was calculated. The values are shown in the table below.

Table 2. Lighting Design

Room	Area (ft2)	Illuminance required (lm/ft2)	Lumens required per room (lm)	Lumens of bulb (lm)	Number of bulbs (ea)	Watts (W)	Usage (hrs in a day)	Number of rooms (ea)	Net Energy consump-tion (kWh/yr)
Dining	342	10	3420	1500	2	14.5	10	1	106
Kitchen	116	20	2320	1500	2	14.5	10	1	106
Living	434	20	8680	1500	6	14.5	15	1	476
Bedroom	100	20	2000	1500	2	14.5	10	4	423
Corridor first floor	76	5	380	800	1	9.5	15	1	52
Bathroom	61	20	1220	1500	1	14.5	5	2	53
Storage first floor	82	5	410	800	1	9.5	2	1	7
Stairway	70	5	350	800	1	9.5	15	1	52
Corridor second floor	250	5	1250	1500	1	14.5	15	1	79
Closet	43	5	215	800	1	9.5	2	1	7
								Total	1362
								Net Energy in MMBTU/year	5

These calculations are for one unit. The annual energy consumption for lighting for one unit is 5 MMBtu/yr.