enable

Your home for today, and tomorrow

Engineering Narrative D8 Submission

August 10, 2017

HOUSE

by Northwestern

Northwestern University

U.S. Department of Energy Solar Decathlon 2017 enable

Your home for today, and tomorrow

HOUSE
by Northwestern

engineering narrative

INTRODUCTION

Enable by House by Northwestern is Northwestern University's first entry in the DOE Solar Decathlon. Designed for active Baby Boomers living in Chicago's North Shore who are looking to downsize and buy their home for life, *Enable* delivers an **EN**ergized (energy-efficient and active lifestyle) and Adapt**ABLE** (the house meets residents' changing needs) experience for its target users. *Enable* is more than a house. It's a home for today, and tomorrow.

AGING-IN-PLACE & UNMET HOUSING NEEDS FOR BABY BOOMERS

Baby Boomers, born between 1946 and 1964, are important to the U.S. housing industry given their sheer numbers. From 2016 to 2060, the population of individuals 65 and older is projected to more than double — from 46 to more than 98 million — which represents an increase from 15 to nearly 24 percent of the total population[1].

In the city of Evanston, IL, home to Northwestern University and part of Chicago's North Shore, 20% of the population is projected to be 65 and older by 2020[2]. A community that takes pride in its age-friendliness, Evanston is one of 284 cities in the world and 45 cities in the United states approved to enter the World Health Organization (WHO) Network of Age-Friendly Cities[3]. Being a part of this network requires that a city adapt its structure and services — including housing — "to be accessible to and inclusive of older people with varying needs and capacities" [4].

Recent Boomer homebuyers aged between 52-61 project they will live in their homes for at least 20 years[5] and approximately 90 percent of those over age 65 report wanting to stay in their homes as long as possible[6]. This desire to **age-in-place** means that Boomers' houses will become important places for long-term care as residents deal with disabilities and other aging-related health challenges. However, the Joint Center for Housing Studies of Harvard University estimates that only 1 percent of the current housing stock contains the key features required to support aging-in-place, such as zero-step entrances, single-floor living, wide hallways and doorways, wheelchair-accessible light switches, and lever-style door handles and faucets[7].

It is with this housing shortage and Evanston's interest in improving its current structures and services to create a culture of age-friendliness in mind that the Solar Decathlon team at Northwestern University set about designing a highly energy-efficient, yet fully-accessible home for a rapidly aging Baby Boomer demographic.

ENABLE: A USER-CENTRIC DESIGN APPROACH

The House by Northwestern (HBN) team took a user-centric approach to the design of *Enable*. In other words, community members weighed in at every step of the design process about how *Enable* could best meet their needs. The buyer personas of "Michael and Lisa", which are referenced frequently in our materials, encompass HBN market research data and represent that common voice of the active Baby Boomer living in Chicago's North Shore.

Based on primary research from HBN User and Market Research Teams[8], our target market ranked the following housing features in order of importance to them: **comfort** and **livability**, **high-performance with functionality**, **easy home maintenance, sustainability,** and **affordability**. The crux of HBN's design efforts was to create a home that balances the needs of the market with our team's desire to create a sustainable, environmentally-friendly home. By packaging energy efficient and sustainable features into a comfortable, beautiful, accessible, and easy-to-maintain home, *Enable* offers sustainability without compromise.

ENGINEERING DESIGN THE RIGHT WAY

Our design process is split into three main parts - optimization, passive techniques, and active systems. We first iterated through many different geometric designs and layouts in collaboration with the architectural design, to compare the performance characteristics of each iteration using energy modeling. After selecting the layout which most met the needs of our users and was optimally efficient, we fine-tuned the passive systems in our design, such as insulation, natural ventilation, and daylighting to improve the comfort and efficiency of our home. Finally, we designed the active systems to be as efficient as possible. Throughout this entire process, we utilized multidisciplinary collaboration with professionals and internal groups to ensure we met all of our user's needs.

DESIGNING FOR CHALLENGING CLIMATE CHARACTERISTICS

Our local climate has the following average characteristics annually:

As shown on the graphs below, Chicago is significantly more humid than Denver, with relative humidity levels averaging between 60-80% year round, compared to 40-50% year round in Denver. ASHRAE 62.1 recommends RH levels be kept below 65% in homes. The Solar Decathlon 2017 Rules further constrain RH to between 35% and 60% for full points.

	CHICAGO	DENVER
CLIMATE ZONE[12]	5	5
HEATING DEGREE DAYS (65F)	6311	5942
COOLING DEGREE DAYS (65F)	842	777
99.6% DESIGN COLD TEMPERATURE[13]	-1.6 F	0.7 F

Table 1. Design temperature parameters for permanent and competition locations

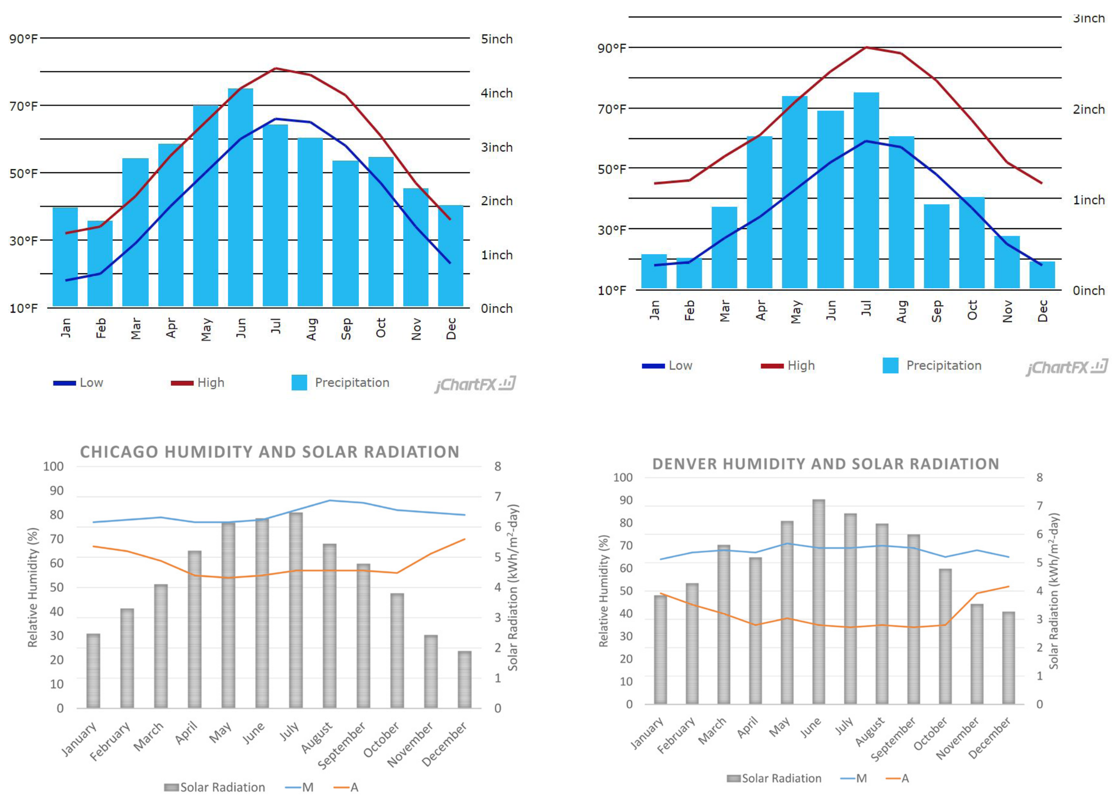

Figure 1. Chicago mean temperature and precipitation data (top left); Chicago mean humidity and solar radiation data (bottom left); Denver mean temperature and precipitation data (top right, note different y-axis scale); Denver mean humidity and solar radiation data (bottom right)[9,10,11]

These climate data points tell us that in Chicago, we will need a significant amount of dehumidification for the home to be comfortable, as well as a capable heating source to heat the home during the winter. To ensure the comfort of *Enable's* future occupants, our engineering design features systems selected specifically for their ability to handle these climatic conditions.

Evanston's latitude corresponds to an optimal solar panel angle of approximately 37 degrees. Using MATLAB simulations, we determined that solar panels maintain near-optimal efficiency as long as they are installed above 20 degrees (Figure 2). Using this information, we incorporated a 23.5 degree slope into the roof design of our home to create a visually appealing and optimally producing solar array.

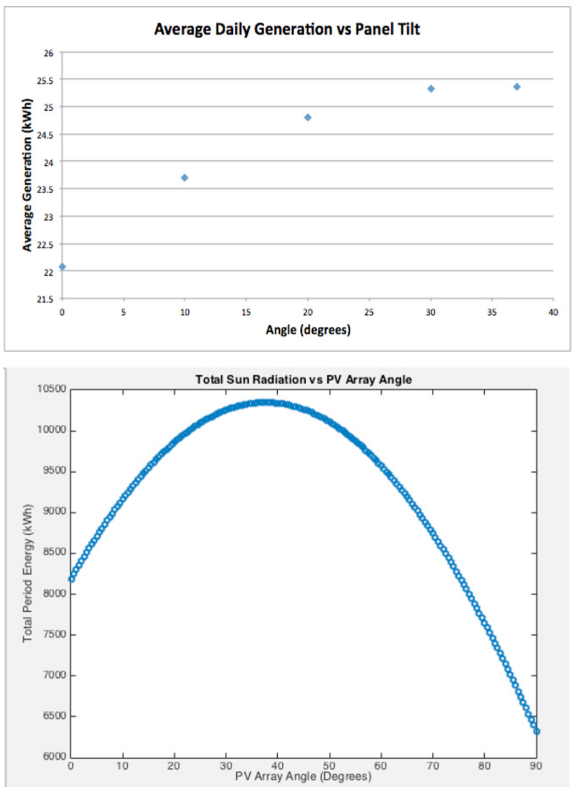

Figure 2. MATLAB output showing optimal solar panel angle in Chicago

OPTIMIZING OUR DESIGN THROUGH COMPREHENSIVE ENERGY MODELING

At the beginning of the Solar Decathlon competition, our team sought to quickly test multiple designs, floor plans, and architectural features. Often times, this "form-finding" process of the design happens without any input from energy modeling or efficiency considerations. To avoid this disconnect, we ensured that each iteration was tested with identical (but still high-performing) insulation values and mechanical systems. Through multiple design charrettes with our mentors at Adrian Smith + Gordon Gill Architecture, we created many schemes using different floor plans, geometry, and orientations. The annual solar production, energy consumption, heating, and cooling loads for each scheme were then compared among iterations. This process was performed with DesignBuilder energy modeling software, with comparisons done in Excel and MATLAB. Each Revit model was imported into the same project template in DesignBuilder, an annual simulation was run, and the resulting data exported for comparison.

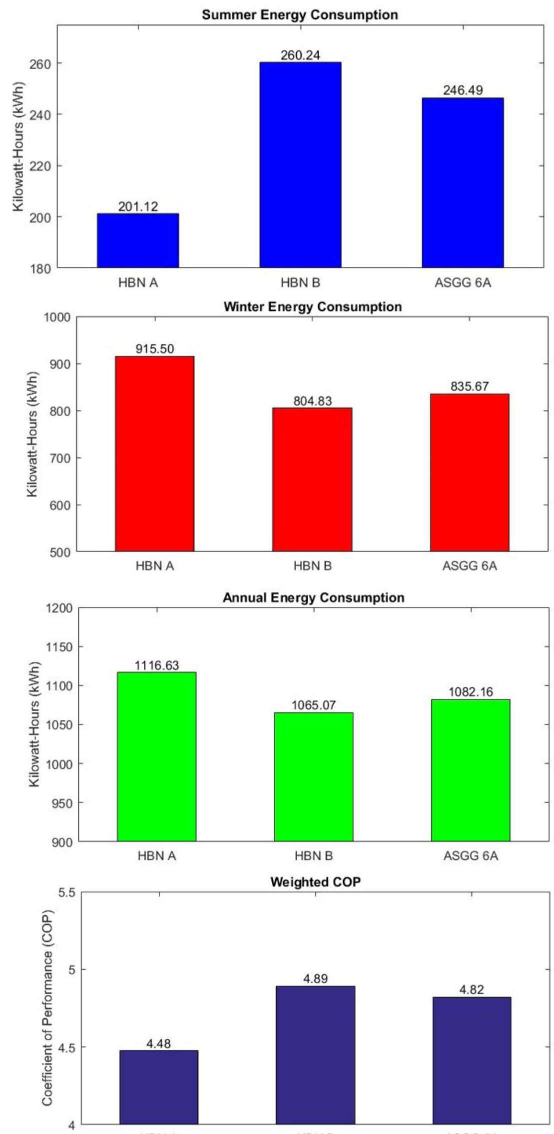

Figure 3. DesignBuilder EnergyPlus simulation for 3 potential layouts, all with varying levels of shading and glazing, reveal that our home is more efficient at cooling than heating. (Weighted COP is avg coefficient of performance for home's mechanical systems, determined by averaging the product of the total sensible heating or cooling loads each day and the COP of the heat pump for that day's temperature.)

We ultimately chose the highest performing design that also met the needs of our user group. After selecting this geometry, we determined final specifications of the building envelope equal to or better than the assumed insulation values and mechanical systems modeled. We then used WufiPassive[14], with the PHIUS+ 2015[15] standards, to analyze our design. This allowed us to obtain very detailed results on the simulated performance of our home. We appreciate the support of the Passive House Alliance in Chicago for their assistance with performing these modeling simulations, the results of which can be viewed in Appendix B.

In order to simulate a competition, we also created a spreadsheet to capture the daily consumption in alignment with competition tasks. Due to the specific nature of competition events and the accuracy we desired, it proved more effective to model the home using known equipment wattages on an hourly basis than using a packaged modeling software. We estimated HVAC loads using modeling software results for the month of October, as well as an additional energy "cushion" resulting from public tours and fully opening the house during many days, which will add additional HVAC loads. This analysis can be viewed in Appendix C, but the end result is a confirmation that our home will produce more energy than we will use during the Solar Decathlon.

A ROBUST BUILDING ENVELOPE IN A SMALL PACKAGE

INSULATION

We determined the insulation types and thicknesses used in our home through energy modeling of different situations, building code, and passive house recommendations. Our walls are composed of 6-3/8" SIP panels, with 5-½" of R-7 per inch closed cell polyurethane foam. The entire assembly of the walls provides an effective R-value of 40.5. However, this R-value hides the fact that there are nearly no thermal bridges throughout the walls of *Enable*. Our SIP panels utilize one-piece corners, allowing the continuous insulation barrier to wrap around the corner rather than be stopped by framing members in the corners.

The roof is constructed with the same size SIP panels as the walls, with the addition of a 6" metal stud framing cavity with R-23 Mineral Wool insulation on the interior face. The SIP panels are placed over Parallel Strand Lumber beams and columns running the length of the home. The total effective R-value of the roof assembly (at its minimum) is R-56.8. Over the flat portion of *Enable*'s roof, there is additional tapered polyiso insulation. The roof has a continuous insulation barrier provided by our SIP panels, a feature often not found in traditional roof construction. Finally, the floor assembly is composed of wood I-joists, filled with 7-¼" R-30 mineral wool insulation. R-value calculations can be viewed in Appendix D. The foam used in our SIP panels serves as the air barrier. Caulk applied around the edges of our SIP panels further seals any lingering gaps, and all penetrations through the thermal envelope are sealed with insulating and airtight foam. These features all come together to ensure an airtight and well-insulated envelope. In addition, the moisture barrier created by the ZIP system sheathing used on the exterior of the SIP panels, combined with the excellent resistance to mold/mildew of our SIP foam[16], prevents any moisture issues within the home or the wall cavity. All HVAC controls have the ability to set a vacation mode, intentionally lowering only the humidity levels in the home without using excess energy for heating or cooling. This protects against any moisture issues while away, while still saving energy. Additional information about our SIP insulation can be found in Appendix E.

WINDOWS

Enable features triple-pane krypton-argon windows with U-values of approximately 0.21 and SHGCs of 0.35. Full technical details for each opening can be found in Appendix F. All windows and doors are EnergyStar Certified. Openings were strategically placed to ensure optimal comfort within the home. The majority of openings are placed on the south facade of the home, to let in sunlight and heat during the winter. Windows on the north side of the home let in soft light throughout the day, illuminating the main living space. The east and west facades have very few openings to minimize morning and evening glare.

LEVERAGING PASSIVE DESIGN TECHNIQUES TO REDUCE ENERGY LOAD

NATURAL LIGHT

Enable incorporates natural light throughout the interior of the home. As we are competing in the Solar Decathlon, we chose to utilize the sun for more than just electrical power. Our Solatube skylight tubes, as well as our clerestory windows and large glass doors in the main living space, brighten the interior and reduce the need for any artificial lighting during the day. Within our second bathroom, a Solatube and daylight harvesting LED light provide plenty of light to the only room in the house without a window. The remaining two solatubes in the entry vestibule also have daylight harvesting LEDs, to ensure more than adequate light for putting on one's shoes and coat on the way out the door.

NATURAL VENTILATION

All of *Enable's* exterior rooms have operable windows, allowing for natural ventilation when desired. Our operable high clerestories on the north, coupled with the sliding doors on the south face, allow for passive cross-ventilation, allowing warm air to rise up and out through the clerestories and drawing cool air in through the south doors. Additionally, our entry vestibule has a venting picture window to allow for passive regulation of the temperature in that space when needed.

PASSIVE THERMAL BUFFER SPACES

In conventional buildings, significant amounts of energy are lost due to air changes during the winter months, with air lost through doors accounting for a significant portion of this loss. Commercial buildings commonly have airlock spaces with multiple doors to gain entry, either through a vestibule or revolving door which meters the amount of conditioned air lost to the outside. This approach is rarely used in residential construction. *Enable*, however, uses this technique to reduce energy losses within the home while at the same time providing a sheltered passageway to the garage during inclement weather. The vestibule approach to the front door also creates an unconditioned space which serves as a mud-room for dirty shoes or wet coats.

While not actively heated, this space does benefit from a large glazing fraction on the south facade, allowing for large amounts of solar gain into the room. The insulated envelope in this room retains the heat for longer than an uninsulated room would, and serves as a sort of "double-wall" for the bordering walls touching the interior of the home. Simulations with DesignBuilder predict this room will not drop below freezing during a typical Chicago winter, and with standard winter solar gains could reach temperatures in the mid-50s during cold winter days. Such significant gain from passive solar energy makes the entryway a functional space year-round.

The sunroom of the home also serves as an additional buffer space. Its roof glazing has a SHGC of 0.83, allowing a significant portion of solar gain into the space, tempering it during the spring and fall and allowing for extended use of the space as a three-season room. In the summer, this space can serve as a buffer to high solar gains through the south sliding window, and is easily vented. The operable center panels of the sunroom enclosure can slide aside, converting the enclosed deck space into an open deck area and allowing for use in multiple capacities.

ACTIVE SYSTEMS ENHANCE A STRONG PASSIVE DESIGN

HEATING, VENTILATION, AND AIR CONDITIONING

Our HVAC system is exactly sized to meet the thermal comfort and indoor air quality needs of our home's future occupants. After we finalized the geometry and thermal envelope components of *Enable*, we ran a TRACE 700 load simulation with the assistance of The Hill Group (Appendix G). We then designed the HVAC system with the most efficient equipment available. This process ensures that *Enable* will efficiently maintain occupant comfort in Evanston year-round, regardless of seasonal variations in weather.

The primary heating and cooling of the home is provided by a high-efficiency air-source heat pump, the **Chiltrix CX34.** This unit recently underwent AHRI certification (Appendices H and I), and obtained a record-setting AHRI IPLV cooling efficiency rating of EER 23.02 (COP 6.75). By running our chiller at non-standard leaving-water temperatures (LWT), we can reach EER 30.72 (COP 9.0), all while maintaining thermal comfort in the home. This unit also utilizes a dynamic humidity controller (DHC), which modulates the LWT temperature based on the dew point of the indoor air to cool without dehumidification when it is not needed, or to significantly dehumidify the air if desired (Figure 4). This allows for accurate control of interior humidity levels, as the DHC constantly checks the interior conditions against its setpoints. An in-depth whitepaper on this control system is available in Appendix J.

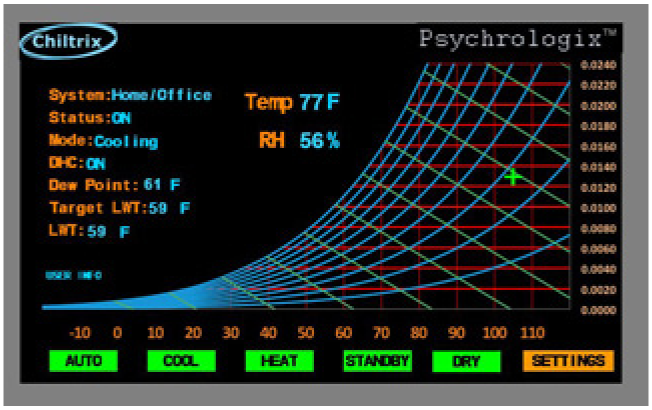

Figure 4. Main screen of Dynamic Humidity Controller[17]

In wintertime, the chiller can still provide sufficient heat for the home. At -4F, the design minimum temperature, the unit can still provide 16,000 BTU/h of heating capacity at a COP of 2.31. Below this temperature, backup heating elements within the home are enabled to protect the compressor in the chiller from cold damage. This temperature, while reached occasionally in the Chicago area, is rarely seen for significant periods of time. The efficiency of the unit increases at higher temperatures, reaching as high of a COP as 3.92.

The chiller capacity is variable to below 25% of design load for both heating and cooling. This ensures that the capacity always matches the load experienced within the home. Our air handler also uses a variable-speed ECM motor, reducing fan energy and allowing slow ramping up of the system to meet the cooling load as desired. This is less noticeable from an occupant perspective as the air handler never experiences quick ramp-ups or suddenly increases airflow dramatically.

Finally, our chiller also provides heat for our domestic hot water tank. Rather than requiring an additional heat pump for standard heat pump water heaters, we can use the same outdoor unit for water heating. This unique approach requires fewer hardware components, and thus has smaller equipment costs. It also provides an efficiency benefit over traditional heat pump water heaters. Rather than cannibalizing heat from the air within the home to heat the water heater, our system pulls heat from the exterior to heat our domestic hot water. This reduces HVAC energy consumption significantly, while still retaining the efficiency benefits of heat pump water heating (Figure 5).

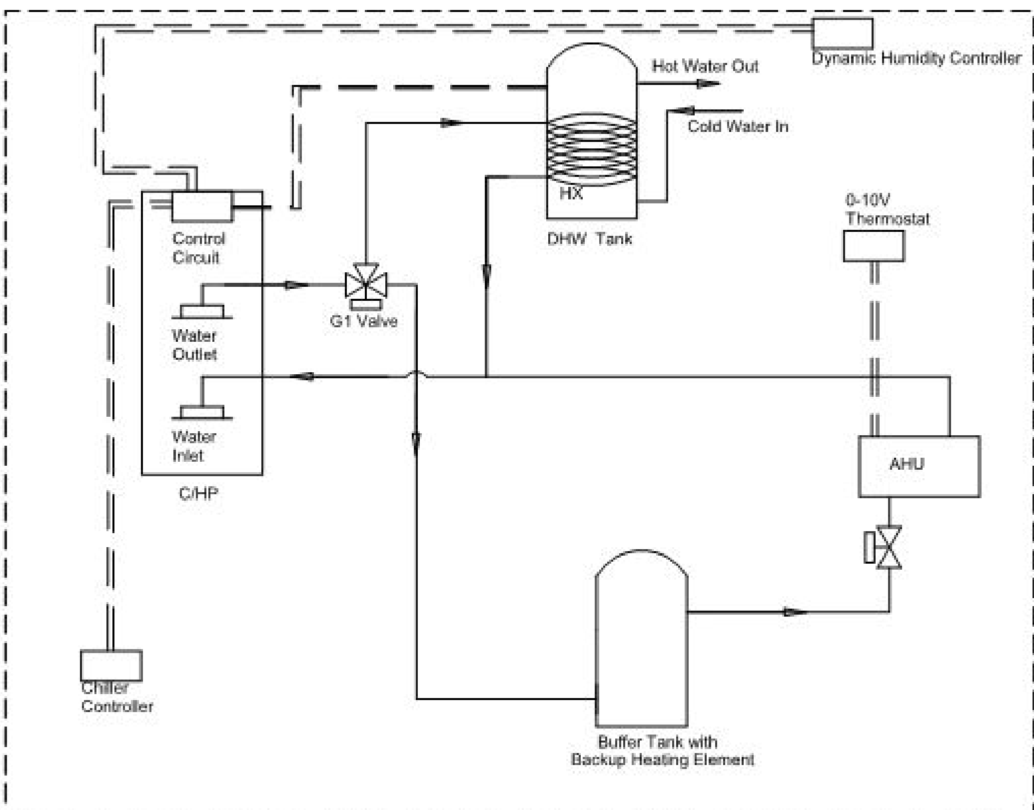

Figure 5. CAD flow diagram of conditioning system

MAINTAINING INDOOR AIR QUALITY

Indoor air quality is an important part of *Enable's* design. The primary feature supporting this is our dedicated ventilation system, which uses the **Zehnder ComfoAir 200**. This unit has a 92% effective heat recovery rating and is a Certified Passive House Component (Appendix K). This unit provides exhaust ventilation from both bathrooms and the kitchen, and supplies fresh air into the return air duct, which is then distributed to every room within the home.

In addition to the ventilation system, we have incorporated three passive IAQ-improving products into our design. First, all of our drywall is **AirRenew Drywall** by CertainTeed. This drywall product actively absorbs airborne formaldehyde and converts it into a safe, inert compound, improving indoor air quality over the long term. We also have used **PURETi**, a photocatalytic titanium dioxide coating that actively removes VOCs and other pollutants from the air. This coating is present on all inward facing glass surfaces in the home, as well as the sunroom and engineered wood siding along the east, south, and west facades of the home. Finally, we have two large living walls which reduce indoor air pollutant levels, serving as live air filters. Not only do we incorporate these features into our home - we also monitor indoor pollutant levels with **Awair**, a smart device that tracks temperature, relative humidity, CO_2, dust, and chemical levels within the home and provides real-time feedback with a user-friendly interface (Image 1). This smart sensor also provides visual and actionable suggestions to improve indoor air quality.[18]

Image 1. Awair indoor air quality monitor. Source: getawair.com

EFFICIENT ELECTRICAL DESIGN

Our home utilizes a **6.5 kW DC-coupled, roof integrated solar array** with a **25 kWh AGM battery bank** designed specifically for solar applications (Figure 6). Our PV system is fully integrated into the roofing system, with no roofing finish material below the solar panels. This allows the PV panels to be installed by roofers directly onto the roof deck, rather than on racking placed over shingles, reducing long-term maintenance costs associated with re-roofing.

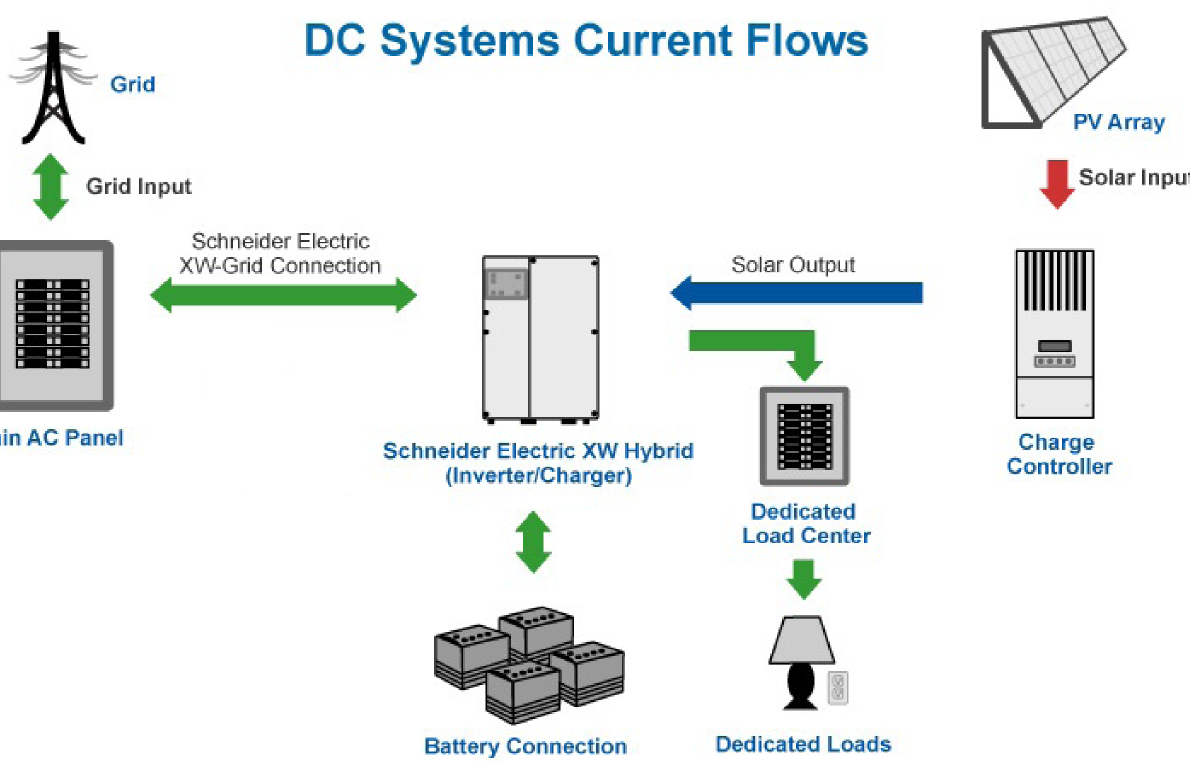

Figure 6. Conceptual diagram of a DC-Coupled solar system[19]

The inclusion of battery storage also enables us to increase our self-consumption fraction significantly over standard net-metered homes. Rather than selling solar energy back to the grid during the day, that excess energy is stored in the battery bank and used in the evening, allowing solar energy to power the home 24 hours a day.

The DC-coupled system configuration provides a resilient system which allows the solar panels to continue to power the home and charge the battery bank in the event of a power loss. All lighting, outlets, HVAC components, and appliances except for the range are backed up by this panel. Depending on energy consumption within the home and solar power production, *Enable* could operate off-grid indefinitely. This is a notable and unique benefit to our home, as AC-coupled or non-storage systems cannot use solar panels without a grid connection, thus requiring a fossil fuel generator if backup power is ever needed.

Enable features **LED lighting** exclusively. The lighting design was performed with the help of photometric design tools and the input of our electrical contractor and lighting distributor, Kelso-Burnett Co. and Paramont EO (Image 2). This enabled us to confirm our light levels meet and exceed both competition requirements and recommended lighting levels for each space within the home prior to construction.

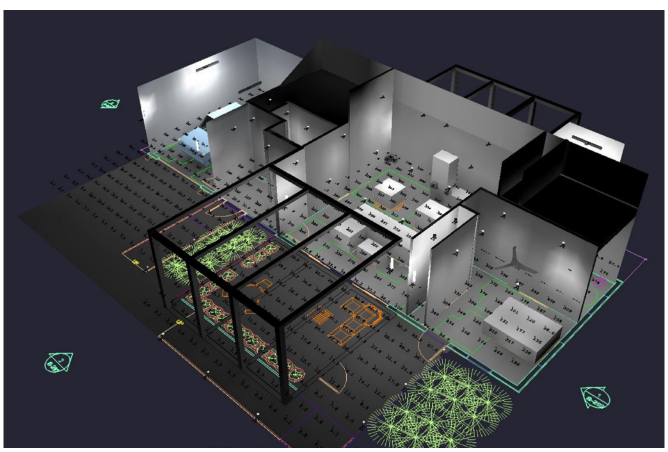

Image 2. Photometric lighting design model screenshot[20]

SMART HOME SYSTEMS STREAMLINE HOME OPERATIONS

Enable includes a host of user-friendly smart home systems, intended to make the operation of the home simpler and more intuitive. All light fixtures are controlled by the **Lutron Caseta** system, which allows occupants to dim all light fixtures, schedule when they are turned on, and create custom lighting scenes and programs. All of this can be done from within the home, or within the Caseta App anywhere with an internet connection.

The Caseta system can do more than just lighting controls: in *Enable*, it integrates with the **Nest Protect** smoke and carbon monoxide detectors, the **Nest Learning Thermostat**, and **Amazon Alexa**. Through the smart-bridge, all of these components can be linked together through one App, preventing users from needing to switch applications frequently to use different features of the home.

To help *Enable's* occupants monitor their energy usage, our home features the **Wiser Energy Center** from Schneider Electric, a fully integrated OEM electrical monitoring system that monitors every circuit within the home. It is the only fully UL-certified residential smart panel available today which provides a clear, visionable, and actionable view of home energy consumption (Figure 7). The end user interface is simple to use and cleanly displays energy consumption for each circuit or load type, removing unnecessary clutter and overly technical information from common monitoring system graphs. These more detailed data points are still usable and can be analyzed both internally to the Wiser energy interface and externally through data exports.

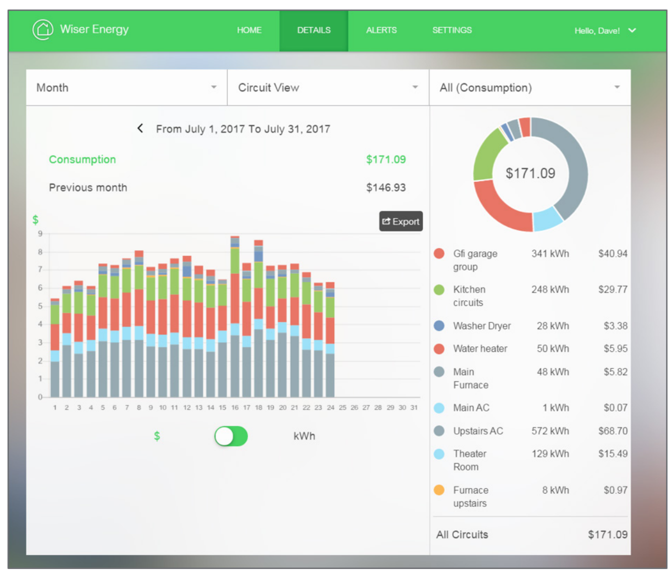

Figure 7. Wiser Energy Center user interface[21]

EASY HOME OPERATION AND MAINTENANCE

While some technologically advanced homes have complicated maintenance requirements, *Enable* requires less user maintenance than a standard house. The ERV unit recommends changing filters once every six months, while the air handler filter should be changed once per month for optimal efficiency and indoor air quality. This is in-line with standard maintenance frequencies for standard furnaces and air handlers.

Beyond this, no additional regular maintenance is required for the HVAC, plumbing, or electrical systems. Our residential battery uses sealed AGM batteries, which requiring no maintenance or electrolyte replenishment. The solar and battery system, dynamic humidity controller, and ventilation system will run self-sufficiently after initial setup, and the learning thermostat can adapt and evolve with users as their preferences or schedules change over time. No overly technical interaction is needed to operate the home beyond a normal knowledge of residential systems, something all of our target demographic will possess.

All major equipment pieces, such as the solar panels, heat pump, and electrical gear is designed for a 20+ year service life. This ensures that *Enable's* occupants do not have to worry about replacing or repairing equipment for many years.

CONCLUSION:

By closely integrating our team from the start with our target customer demographic and practitioners of construction and energy technologies, as well as architecture and design, we effectively integrated research, modeling, multidiscipline collaboration, and cutting-edge technologies through our engineering approach. By taking a user-centric approach to marry the ingenuity and creativity of our student team members with the discipline and know-how of industrial leaders, we believe we have created a harmonious product in *Enable* that is both high-performing and beautiful.

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15. http://www.phius.org/phius-2015-new-passive-building-standard-summary
16. According to ASTM D-543-95 (2001)
17. Image from www.chiltrix.com
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20. Design Software screenshots courtesy of Paramont-EO
21. Image courtesy of Schneider Electric

APPENDICES

APPENDIX A: RENDERINGS

APPENDIX B: WUFIPASSIVE MODEL RESULTS (CREDIT TO PASSIVE HOUSE ALLIANCE CHICAGO)

APPENDIX C: COMPETITION ENERGY MODELING SPREADSHEET

APPENDIX D: R-VALUE CALCULATIONS

APPENDIX E: TECHNICAL DATA ON PU FOAM (CREDIT TO ECO-PANELS)

APPENDIX F: DOOR AND WINDOW SCHEDULE

APPENDIX G: TRACE 700 MODEL (CREDIT TO THE HILL GROUP)

APPENDIX H: SPEC SHEET FOR CX34

APPENDIX I: AHRI CERTIFICATE

APPENDIX J: DHC WHITEPAPER (FROM CHILTRIX)

APPENDIX K: PH CERTIFICATE FOR ZEHNDER

APPENDIX A: RENDERINGS

Image A1. Overhead exterior view from the southeast, Summer

Image A2. Exterior view from the southeast, Winter

Image A3. Exterior view from the southeast.

Image A4. Exterior view from the southwest.

Image A5. Interior view from front door, looking into the living room, dining room, and kitchen.

Image A6. Interior view from door to the convertible room, looking into the living room and out to the sunroom.

Image A7. Interior view of the master bedroom; door to the right exits to the sunroom.

Image A8. Interior view of the master bathroom.

Image A9. Interior view of the convertible room, looking out to the dining room and kitchen.

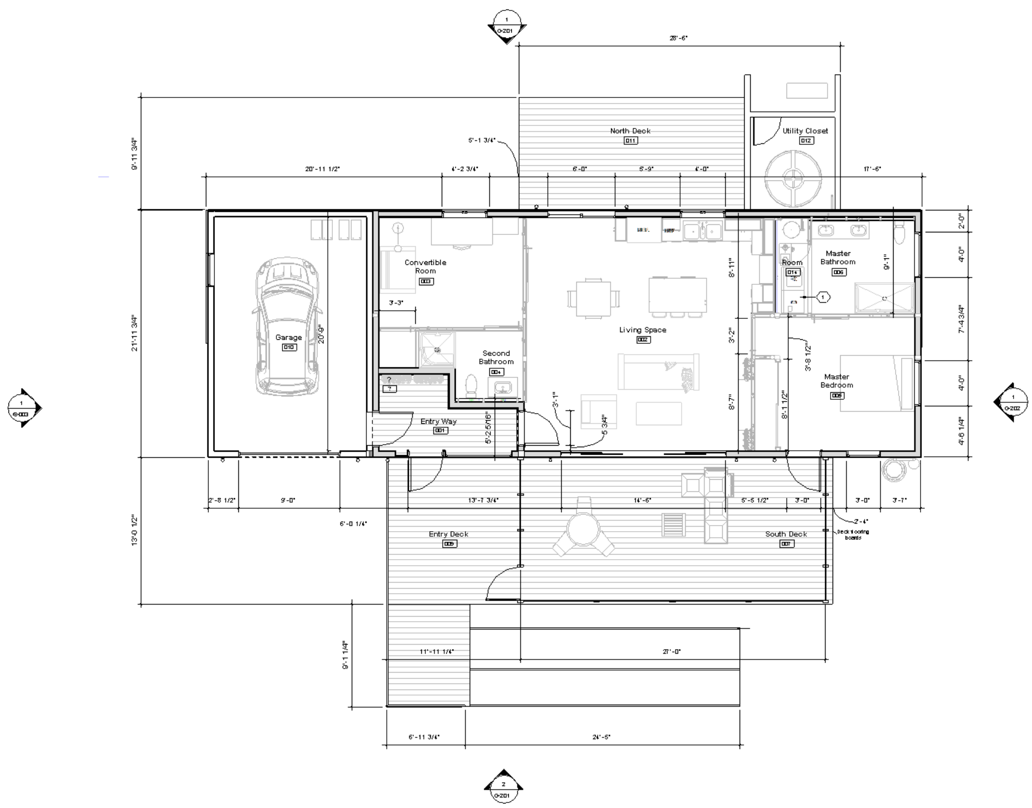
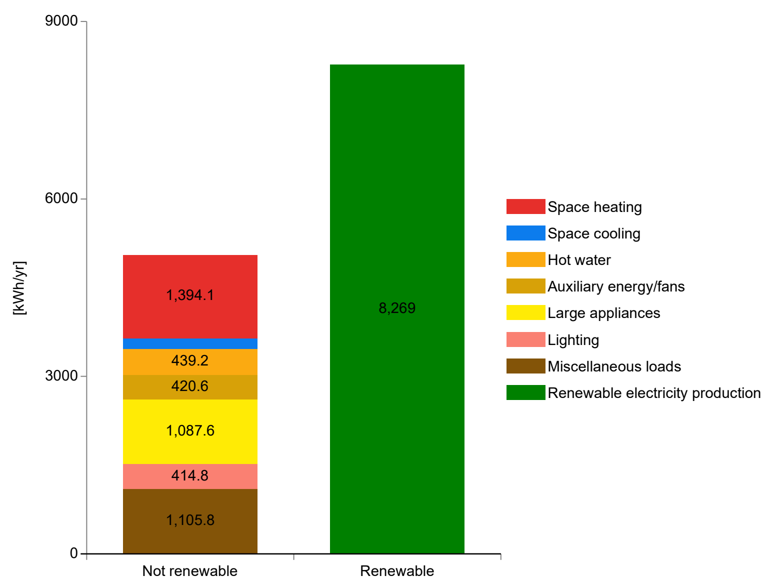


Image A10. Floor plan.

PHIUS+ 2015 SITE ENERGY REPORT 1

Project name:	**Northwestern - As Designed**	
Climate:	**CHICAGO OHARE INTL AP IL (Monthly)**	
Type:	**Residential**	
Interior conditioned floor area:	**913.4**	ft²
Number of units:	**1**	
Occupants:	**2**	
Site energy use:	**-10,976.5**	kBtu/yr
Specific site energy use:	**-12**	kBtu/ft²yr
Site energy use:	**-3,217.2**	kWh/yr
Specific site energy use:	**-3.5**	kWh/ft²yr
Site energy use per person:	**-1,608.6**	kWh/Person yr
Net site energy use (with 100% renewables):	**-10,976.5**	kBtu/yr
Specific net site energy use (with 100% renewables):	**-12**	kBtu/ft²yr
Net site energy use (with 100% renewables):	**-3,217.2**	kWh/yr
Specific net site energy use (with 100% renewables):	**-3.5**	kWh/ft²yr
Net site energy use per person (with 100% renewables):	**-1,608.6**	kWh/Person yr

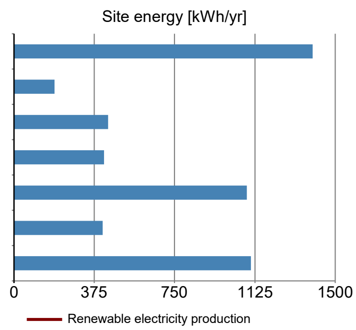
OVERVIEW



PHIUS+ 2015 SITE ENERGY REPORT

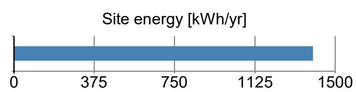
TOTAL USE BY TYPE

Type	Site Energy [kWh/yr]	Specific site energy [kWh/ft² yr]	Site Energy [kBtu/yr]	Specific Site Energy [kBtu/ft² yr]
Space heating	1,394.1	1.5	4,756.3	5.2
Space cooling	189.7	0.2	647.3	0.7
Hot water	439.2	0.5	1,498.6	1.6
Auxiliary energy/fans	420.6	0.5	1,435	1.6
Large appliances	1,087.6	1.2	3,710.6	4.1
Lighting	414.8	0.5	1,415.3	1.5
Miscellaneous loads	1,105.8	1.2	3,772.6	4.1
Renewable electricity production	-8,269	-9.1	-28,212.2	-30.9
Total	**-3,217.2**	**-3.5**	**-10,976.5**	**-12**



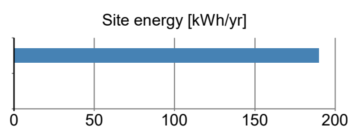
SPACE HEATING

Type	Site Energy [kWh/yr]	Specific site energy [kWh/ft² yr]	Site Energy [kBtu/yr]	Specific Site Energy [kBtu/ft² yr]
Heat pump	1,394.1	1.5	4,756.3	5.2
Total	**1,394.1**	**1.5**	**4,756.3**	**5.2**



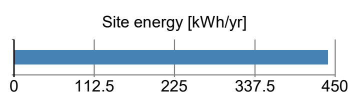
SPACE COOLING

Type	Site Energy [kWh/yr]	Specific site energy [kWh/ft² yr]	Site Energy [kBtu/yr]	Specific Site Energy [kBtu/ft² yr]
Recirculation Cooling	189.7	0.2	647.3	0.7
Dehumidification	0	0	0	0
Total	**189.7**	**0.2**	**647.3**	**0.7**



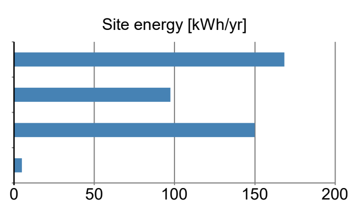
DHW

Type	Site Energy [kWh/yr]	Specific site energy [kWh/ft² yr]	Site Energy [kBtu/yr]	Specific Site Energy [kBtu/ft² yr]
Heat pump	439.2	0.5	1,498.6	1.6
Total	**439.2**	**0.5**	**1,498.6**	**1.6**



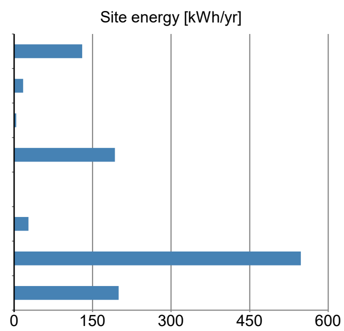
AUXILIARY ENERGY/FANS

Type	Site Energy [kWh/yr]	Specific site energy [kWh/ft² yr]	Site Energy [kBtu/yr]	Specific Site Energy [kBtu/ft² yr]
Ventilation winter	168.4	0.2	574.6	0.6
Ventilation Defrost	97.3	0.1	332.1	0.4
Ventilation summer	149.8	0.2	511.2	0.6
DHW storage load pump	5	0	17.2	0
Total	**420.6**	**0.5**	**1,435**	**1.6**



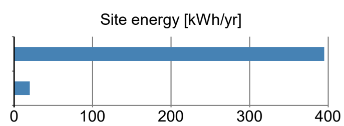
LARGE APPLIANCES

Type	Site Energy [kWh/yr]	Specific site energy [kWh/ft² yr]	Site Energy [kBtu/yr]	Specific Site Energy [kBtu/ft² yr]
Kitchen dishwasher	130	0.1	443.5	0.5
Laundry - washer	17.6	0	59.9	0.1
	(4.4)	(0)	(15.1)	(0)
Laundry - dryer	192.5	0.2	656.8	0.7
Energy consumed by evaporation	0	0	0	0
	(27.7)	(0)	(94.4)	(0.1)
Kitchen fridge/freeze combo	547.5	0.6	1,868	2
Kitchen cooktop	200	0.2	682.4	0.7
Total	**1,087.6**	**1.2**	**3,710.6**	**4.1**



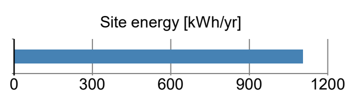
LIGHTING

Type	Site Energy [kWh/yr]	Specific site energy [kWh/ft² yr]	Site Energy [kBtu/yr]	Specific Site Energy [kBtu/ft² yr]
PHIUS+ 2015 Interior lighting	394.8	0.4	1,347	1.5
PHIUS+ 2015 Exterior lighting	20	0	68.3	0.1
Total	**414.8**	**0.5**	**1,415.3**	**1.5**



MISC LOADS

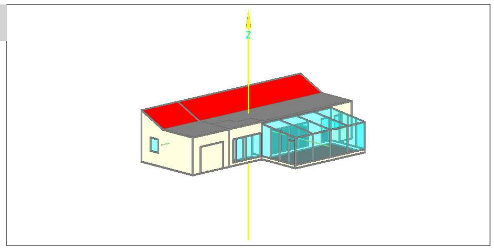
Type	Site Energy [kWh/yr]	Specific site energy [kWh/ft² yr]	Site Energy [kBtu/yr]	Specific Site Energy [kBtu/ft² yr]
PHIUS+ 2015 Misc electric loads	1,105.8	1.2	3,772.6	4.1
Total	**1,105.8**	**1.2**	**3,772.6**	**4.1**



PHIUS+ 2015 VERIFICATION — 1

BUILDING INFORMATION

Category:	**Residential**
Status:	**In planning**
Building type:	**New construction**
Year of construction:	
Units:	**1**
Number of occupants:	**2 (Design)**



Boundary conditions

Climate: **CHICAGO OHARE INTL AP IL (Monthly)**

Internal heat gains:	**1.2**	Btu/hr ft²
Interior temperature:	**68**	°F
Overheat temperature:	**77**	°F

Building geometry

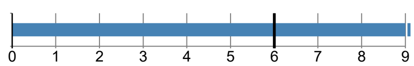
Enclosed volume:	**12,181.4**	ft³
Net-volume:	**9,257.9**	ft³
Total area envelope:	**3,795.2**	ft²
AV ratio:	**0.3**	1/ft
Floor area:	**913.4**	ft²

PASSIVEHOUSE REQUIREMENTS

Certificate criteria: **PHIUS+ 2015 Standard**

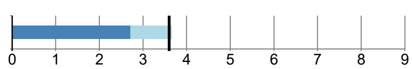
Heating demand

specific:	**17.71**	kBtu/ft²yr
target:	**6**	kBtu/ft²yr
total:	16,176.2	kBtu/yr



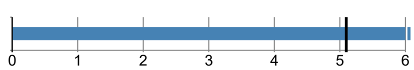
Cooling demand

sensible:	**2.71**	kBtu/ft²yr
latent:	**0.95**	kBtu/ft²yr
specific:	**3.65**	kBtu/ft²yr
target:	**3.6**	kBtu/ft²yr
total:	3,335.53	kBtu/yr



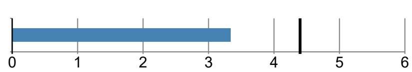
Heating load

specific:	**10.12**	Btu/hr ft²
target:	**5.1**	Btu/hr ft²
total:	9,245.78	Btu/hr



Cooling load

specific:	**3.34**	Btu/hr ft²
target:	**4.4**	Btu/hr ft²
total:	3,048.62	Btu/hr

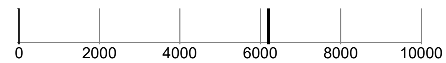


PHIUS+ 2015 VERIFICATION 2

Source energy

PHIUS+ Source Zero: YES

total:	**0**	kWh/yr
specific:	**0**	kWh/Person yr
target:	**6,200**	kWh/Person yr
total:	**0**	kBtu/yr
specific:	0	kBtu/ft²yr

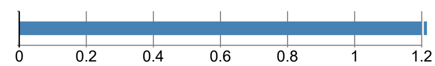


Site energy

total:	-10,976.55	kBtu/yr
specific:	-12.02	kBtu/ft²yr
total:	-3,217.23	kWh/yr
specific:	-3.52	kWh/ft²

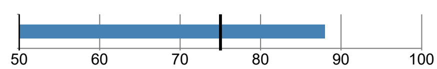
Air tightness

ACH50:	**1.23**	1/hr
CFM50 per envelope area:	**0.05**	cfm/ft²
target:	**1.23**	1/hr
target CFM50:	**0.05**	cfm/ft²

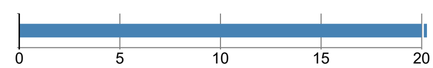


PASSIVEHOUSE RECOMMENDATIONS

HRV efficiency:	**88**	%



Frequency of overheating: Cooling system is required	**21.8**	%

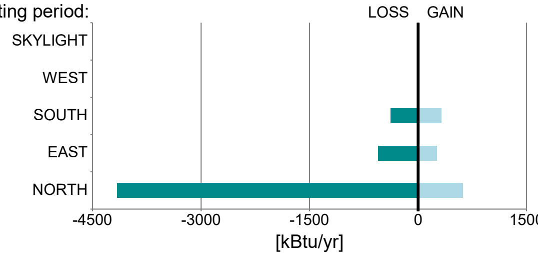


Frequency of overheating only applies if there is not a [properly sized] cooling system installed.

BUILDING ELEMENTS

Windows

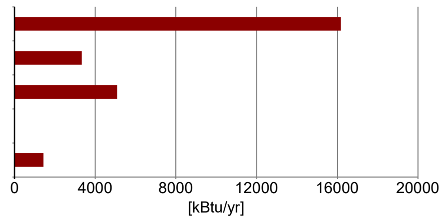
Heat gain/loss heating period:



Average SHGC:	**0.36**	
Average solar reduction factor heating:	**0.32**	
Average solar reduction factor cooling:	**0.42**	
Average U-value:	**0.261**	Btu/hr ft² °F
Total glazing area:	**80.5**	ft²
Total window area:	**126**	ft²

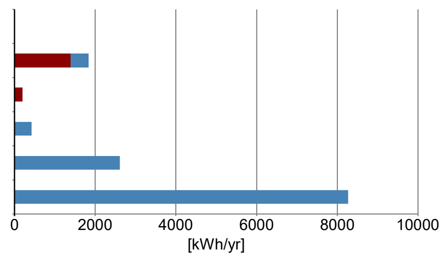
HVAC

Total heating demand:	**16,176**	kBtu/yr
Total cooling demand:	**3,336**	kBtu/yr
Total DHW energy demand:	**5,097**	kBtu/yr
Solar DHW contribution:	**0**	kBtu/yr
Auxiliary electricity:	**1,435**	kBtu/yr



Electricity

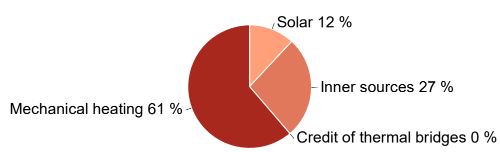
Direct heating / DHW:	**0**	kWh/yr
Heatpump heating:	**1,833**	kWh/yr
Cooling:	**190**	kWh/yr
HVAC auxiliary energy:	**421**	kWh/yr
Appliances:	**2,608**	kWh/yr
Renewable generation, coincident production and use:	**8,269**	kWh/yr
Total electricity demand:	**0**	kWh/yr



HEAT FLOW - HEATING PERIOD

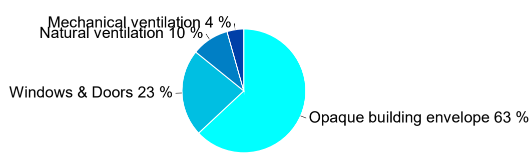
Heat gains

Solar:	**2,759**	kBtu/yr
Inner sources:	**6,250**	kBtu/yr
Credit of thermal bridges:	**0**	kBtu/yr
Mechanical heating:	**16,176**	kBtu/yr



Heat losses

Opaque building envelope:	**15,888**	kBtu/yr
Windows & Doors:	**5,723**	kBtu/yr
Natural ventilation:	**2,458**	kBtu/yr
Mechanical ventilation:	**1,115**	kBtu/yr

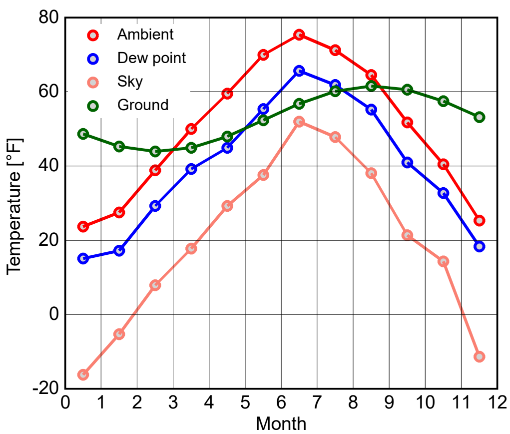


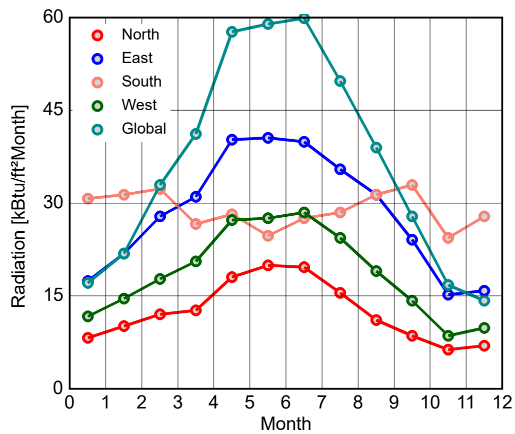
CLIMATE

Latitude:	**42**	°
Longitude:	**-87.9**	°
Elevation of weather station:	**659.4**	ft
Elevation of building site:	**659.4**	ft
Heat capacity air:	**0.018**	Btu/ft³F
Daily temperature swing summer:	**18.7**	°F
Average wind speed:	**13.1**	ft/s

Ground

Average ground surface temperature:	**51.7**	°F
Amplitude ground surface temperature:	**57.8**	°F
Ground thermal conductivity:	**1.2**	Btu/hr ft °F
Ground heat capacity:	**29.8**	Btu/ft³F
Depth below grade of groundwater:	**9.8**	ft
Flow rate groundwater:	**0.2**	ft/d





Calculation parameters

Length of heating period:	**273**	days/yr
Heating degree hours:	**154.9**	kFh/a
Phase shift months:	**NaN**	mths
Time constant heating demand:	**69.6**	hr
Time constant cooling demand:		

Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3

Climate for		Heating load 1	Heating load 2	Cooling
Temperature	[°F]	7.5	21.2	80.8
Solar radiation North	[Btu/hr ft²]	11.4	11.4	28.2
Solar radiation East	[Btu/hr ft²]	35.8	15.5	64.7
Solar radiation South	[Btu/hr ft²]	67.2	23.8	43.1
Solar radiation West	[Btu/hr ft²]	19.7	13.6	42.8
Solar radiation Global	[Btu/hr ft²]	27.6	20.3	95.1

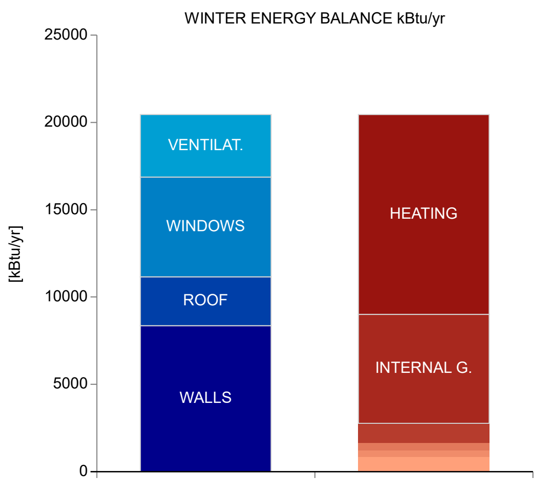
Relevant boundary conditions for heating load calculation: Heating load 1

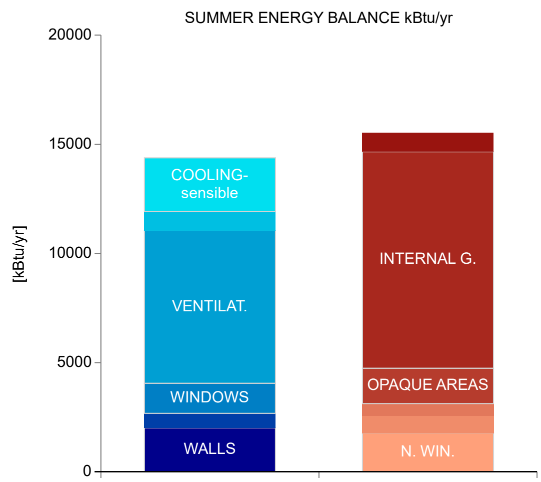
ANNUAL HEAT DEMAND

Transmission losses :	**21,612**	kBtu/yr
Ventilation losses:	**3,573**	kBtu/yr
Total heat losses:	**25,185**	kBtu/yr
Solar heat gains:	**3,131**	kBtu/yr
Internal heat gains:	**7,092**	kBtu/yr
Total heat gains:	**10,223**	kBtu/yr
Utilization factor:	**88.1**	%
Useful heat gains:	**9,009**	kBtu/yr
Annual heat demand:	**16,176**	kBtu/yr
Specific annual heat demand:	**17,711.6**	Btu/ft²yr

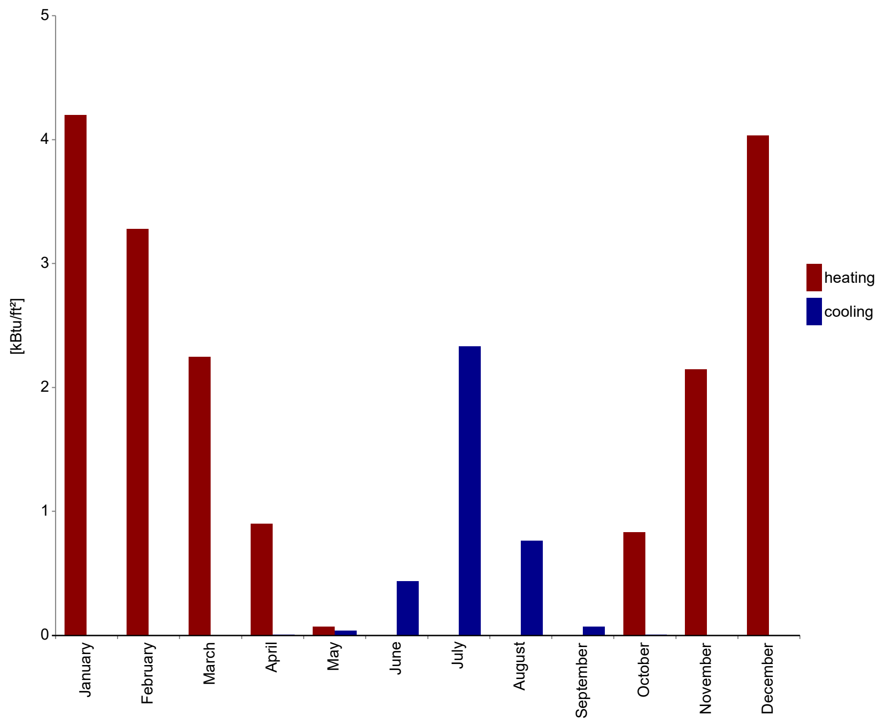
ANNUAL COOLING DEMAND

Solar heat gains:	**4,741**	kBtu/yr
Internal heat gains:	**9,909**	kBtu/yr
Total heat gains:	**14,651**	kBtu/yr
Transmission losses :	**16,468**	kBtu/yr
Ventilation losses:	**22,189**	kBtu/yr
Total heat losses:	**38,658**	kBtu/yr
Utilization factor:	**31.5**	%
Useful heat losses:	**12,179**	kBtu/yr
Cooling demand - sensible:	**2,471**	kBtu/yr
Cooling demand - latent:	**864**	kBtu/yr
Annual cooling demand:	**3,336**	kBtu/yr
Specific annual cooling demand:	**3.7**	kBtu/ft²yr





SPECIFIC HEAT/COOLING DEMAND MONTHLY



Month	Heating [kBtu/ft²]	Cooling [kBtu/ft²]
January	4.2	0
February	3.3	0
March	2.2	0
April	0.9	0
May	0.1	0
June	0	0.4
July	0	2.3
August	0	0.8
September	0	0.1
October	0.8	0
November	2.1	0
December	4	0

HEATING LOAD

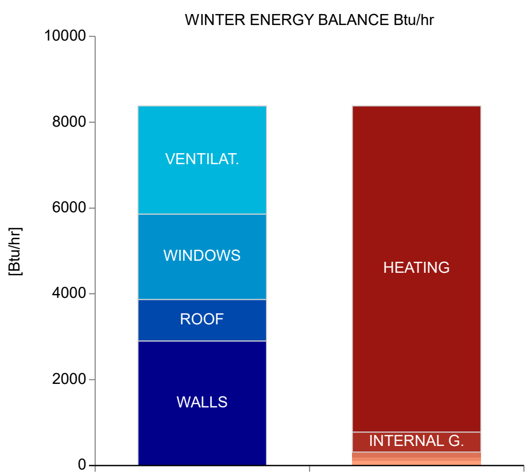
	First climate		Second climate	
Transmission heat losses:	**7,502.4**	Btu/hr	**5,805.5**	Btu/hr
Ventilation heat losses:	**2,520.3**	Btu/hr	**1,950.2**	Btu/hr
Total heat loss:	**10,022.7**	Btu/hr	**7,755.7**	Btu/hr
Solar heat gain:	**313.7**	Btu/hr	**196.4**	Btu/hr
Internal heat gain:	**463.3**	Btu/hr	**463.3**	Btu/hr
Total heat gains heating:	**777**	Btu/hr	**659.7**	Btu/hr
Heating load:	**9,245.8**	Btu/hr	**7,096**	Btu/hr

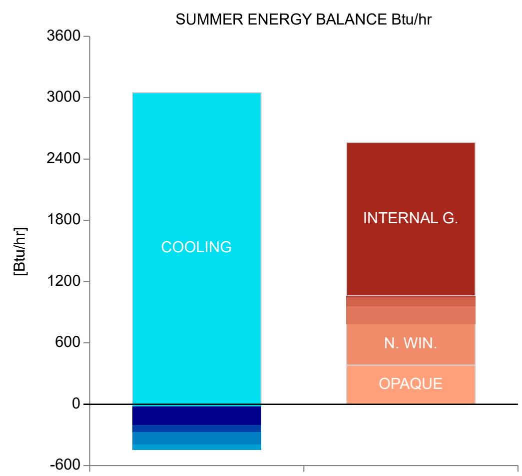
Relevant heating load:	**9,245.8**	Btu/hr
Specific heating load:	**10.1**	Btu/hr ft²

COOLING LOAD

Solar heat gain:	**1,060**	Btu/hr
Internal heat gain:	**1,501.5**	Btu/hr
Total heat gains cooling:	**2,561.5**	Btu/hr
Transmission heat losses:	**-409.2**	Btu/hr
Ventilation heat losses:	**-77.9**	Btu/hr
Total heat loss:	**-487.1**	Btu/hr
Cooling load - sensible:	**3,048.6**	Btu/hr
Cooling load - latent:	**0**	Btu/hr

Relevant cooling load:	**3,048.6**	Btu/hr
Specific maximum cooling load:	**3.3**	Btu/hr ft²





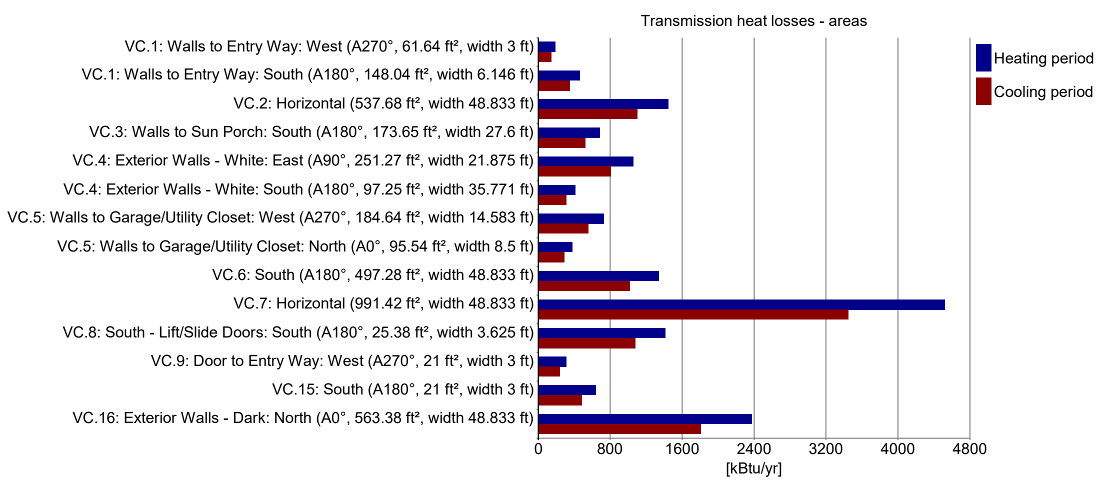
AREAS

Transmission heat losses - areas

Name	Area [ft²]	Average U-value [Btu/hr ft² °F]	Absorption coefficient	Emission coefficient	Reduction factor shading [%]	Transmission losses heating [kBtu/yr]	Transmission losses cooling [kBtu/yr]
VC.1: Walls to Entry Way: West (A270°, 61.64 ft², width 3 ft)	61.6	0.024	0	0	0	192.2	146.5
VC.1: Walls to Entry Way: South (A180°, 148.04 ft², width 6.146 ft)	148	0.024	0	0	0	461.7	351.8
VC.2: Horizontal (537.68 ft², width 48.833 ft)	537.7	0.015	0.8	0.9	100	1447.4	1102.9
VC.3: Walls to Sun Porch: South (A180°, 173.65 ft², width 27.6 ft)	173.6	0.024	0	0	0	686	522.7
VC.4: Exterior Walls - White: East (A90°, 251.27 ft², width 21.875 ft)	251.3	0.024	0.2	0.9	100	1059.1	807.1
VC.4: Exterior Walls - White: South (A180°, 97.25 ft², width 35.771 ft)	97.3	0.024	0.2	0.9	100	409.9	312.4
VC.5: Walls to Garage/Utility Closet: West (A270°, 184.64 ft², width 14.583 ft)	184.6	0.024	0	0	0	729.4	555.8
VC.5: Walls to Garage/Utility Closet: North (A0°, 95.54 ft², width 8.5 ft)	95.5	0.024	0	0	0	377.4	287.6
VC.6: South (A180°, 497.28 ft², width 48.833 ft)	497.3	0.015	0.8	0.9	30	1338.6	1020
VC.7: Horizontal (991.42 ft², width 48.833 ft)	991.4	0.026	0.4	0.9	100	4520.7	3444.8
VC.8: South - Lift/Slide Doors: South (A180°, 25.38 ft², width 3.625 ft)	25.4	0.337	0	0	0	1415.2	1078.4
VC.9: Door to Entry Way: West (A270°, 21 ft², width 3 ft)	21	0.115	0	0	0	315.8	240.7
VC.15: South (A180°, 21 ft², width 3 ft)	21	0.184	0	0	0	639	487
VC.16: Exterior Walls - Dark: North (A0°, 563.38 ft², width 48.833 ft)	563.4	0.024	0.8	0.9	100	2374.6	1809.5

Degree hours [kFh/a]

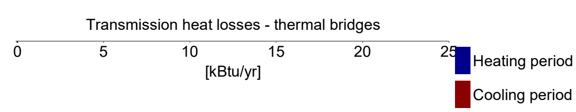
	Heating	Cooling
Ambient heating	96.8	73.8
Ground heating	59.9	84.4



THERMAL BRIDGES

Transmission heat losses - thermal bridges

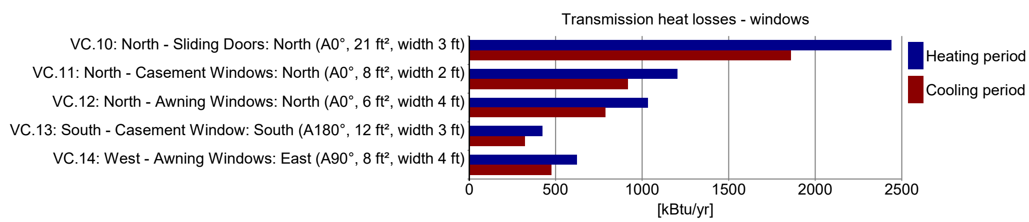
Name	Length [ft]	Psi-value [Btu/hr ft °F]	Transmission losses [kBtu/yr]	Transmission losses cooling [kBtu/yr]

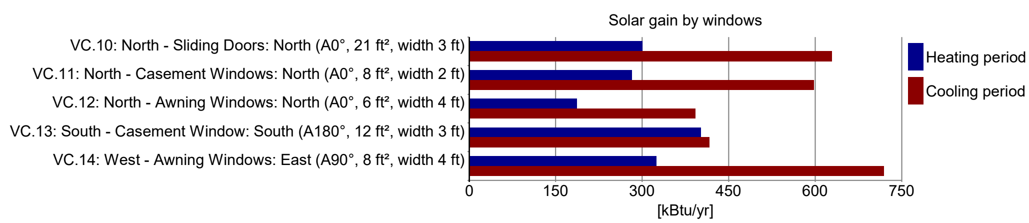


WINDOWS

Transmission heat losses - windows

Name	Quan-tity	Incli-nation [°]	U-value total [Btu/hr ft² °F]	SHGC (perpen-dicular)	Reduction factor shading [%]	Reduction factor shading summer [%]	Solar gain heating [kBtu/yr]	Solar gain cooling [kBtu/yr]	Transmission losses heating [kBtu/yr]	Transmission losses cooling [kBtu/yr]
VC.10: North - Sliding Doors: North (A0°, 21 ft², width 3 ft)	2	90	0.333	0.3	64.6	79.9	300.9	628.7	2,440.3	1,859.5
VC.11: North - Casement Windows: North (A0°, 8 ft², width 2 ft)	4	90	0.216	0.4	60.6	76.1	282.4	598.3	1,203.2	916.8
VC.12: North - Awning Windows: North (A0°, 6 ft², width 4 ft)	4	90	0.247	0.4	58.3	72.5	186.9	392.4	1,033.9	787.8
VC.13: South - Casement Window: South (A180°, 12 ft², width 3 ft)	1	90	0.202	0.4	65.5	74.2	401.4	416.9	422.6	322.1
VC.14: West - Awning Windows: East (A90°, 8 ft², width 4 ft)	2	90	0.224	0.4	58.7	79	324.9	718.7	623.4	475.1





Summary building envelope

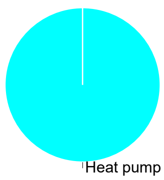
	Total area / length		Average U-value / Psi value		Transmission losses	
Exterior wall ambient:	**1,903.3**	ft²	**0.025**	Btu/hr ft² °F	**8,364.3**	kBtu/yr
Exterior wall ground:	**0**	ft²	**0**	Btu/hr ft² °F	**0**	kBtu/yr
Basement:	**0**	ft²	**0**	Btu/hr ft² °F	**0**	kBtu/yr
Roof:	**1,035**	ft²	**0.015**	Btu/hr ft² °F	**2,786**	kBtu/yr
Windows:	**126**	ft²	**0.261**	Btu/hr ft² °F	**5,723.4**	kBtu/yr
Doors:	**0**	ft²	**0**	Btu/hr ft² °F	**0**	kBtu/yr
Thermal bridge ambient:	**0**	ft	**0**	Btu/hr ft °F	**0**	kBtu/yr
Thermal bridge perimeter:	**0**	ft	**0**	Btu/hr ft °F	**0**	kBtu/yr
Thermal bridge floor slab:	**0**	ft	**0**	Btu/hr ft °F	**0**	kBtu/yr

Shading

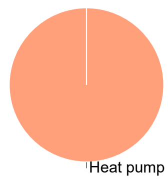
	Heating		Cooling	
Reduction factor North:	**61.5**	%	**76.6**	%
Reduction factor East:	**58.7**	%	**79**	%
Reduction factor South:	**65.5**	%	**74.2**	%
Reduction factor West:	**100**	%	**100**	%
Reduction factor Horizontal:	**100**	%	**100**	%

System	DHW			Heating			Total		
	Covered DHW demand [%]	Estimated solar fraction [%]	Final energy demand [kBtu/yr]	Covered heating demand [%]	Estimated solar fraction [%]	Final energy demand [kBtu/yr]	Performance ratio	CO2 equivalent emissions [lb/yr]	Source energy demand [kBtu/yr]
Heat pump, Chiltrix CX34	100	0	1,498.6	100	0	4,756.3	0.3	2,748.4	19,765.5
Σ	100	0	1,498.6	100	0	4,756.3		2,748.4	19,765.5

DHW - final energy



Heating - final energy



COOLING UNITS

	sensible		latent	
Air cooling:	**0**	kBtu/ft²yr	**0**	kBtu/ft²yr
Recirculation cooling:	**2.7**	kBtu/ft²yr	**2.1**	kBtu/ft²yr
Additional dehumidification:			**0**	kBtu/ft²yr
Panel cooling:	**0**	kBtu/ft²yr		
Sum:	**2.7**	kBtu/ft²yr	**2.1**	kBtu/ft²yr

VENTILATION

Infiltration pressure test ACH50:	**1.23**	1/hr
Total extract air demand:	**65**	cfm
Supply air per person:	**18**	cfm
Occupancy:	**2**	
Average air flow rate:	**50.05**	cfm
Average air change rate:	**0.32**	1/hr
Effective ACH ambient:	**0.13**	1/hr
Effective ACH ground:	**0**	1/hr
Energetically effective air exchange:	**0.13**	1/hr
Infiltration air change rate:	**0.09**	1/hr
Infiltration air change rate (heating load):	**0.22**	1/hr
Type of ventilation system:	**Balanced PH ventilation**	
Wind screening coefficient (e):	**0.07**	
Wind exposure factor:	**15**	
Wind shield factor:	**0.05**	
Ventilation heat losses:	**3,176.21**	kBtu/yr

Devices

Name	HRV / ERV efficiency [-]	Electric efficiency [W/cfm]	Heat recovery efficiency SHX [-]	Effective recovery efficiency [-]
CA200 ERV	0.9	0.04	0	0.9
Altogether	0.9	0.04	0	0.9

Ducts

Name	Length (total) [ft]	Clear cross-section [ft²]	U-value [Btu/hr ft² °F]	Assigned ventilation units
Supply / outdoor air duct	8	0.1963	1.36	CA200 ERV
Extract / Exhaust air duct	3	0.1963	1.36	CA200 ERV
∑	11			

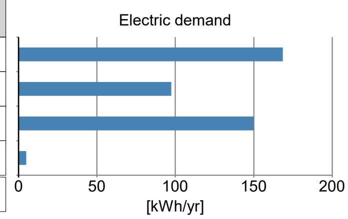
*length * quantity ** thermal conductivity / thickness

SUMMER VENTILATION

ACH night ventilation:	**0.3**	1/hr
ACH natural summer:	**0**	1/hr
Mechanical ventilation summer:	**0.3**	1/hr
Mechanical ventilation summer with HR:	**no**	
Preferred minimum indoor temperature for night ventilation:	**68**	°F
Overheating temperature:	**77**	°F

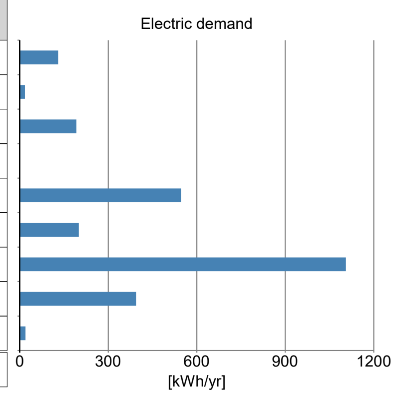
ELECTRICITY DEMAND - AUXILIARY ELECTRICITY

Type	Quantity	Indoor	Norm demand	Electric demand [kWh/yr]	Source energy [kBtu/yr]
Ventilation winter	1	yes	0.7 W/cfm	168.4	1815.7
Ventilation Defrost	1	yes	316.6 W	97.3	1049.4
Ventilation summer	1	yes	0.7 W/cfm	149.8	1615.3
DHW storage load pump	1	yes	50.5 W	5	54.2
Σ				420.6	4534.6



ELECTRICITY DEMAND RESIDENTIAL BUILDING

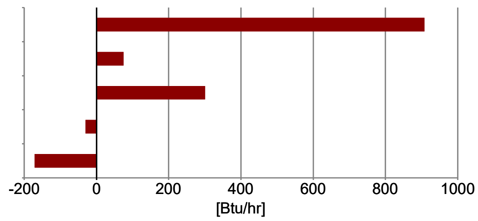
Type	Quantity	Indoor	Norm demand	Electric demand [kWh/yr]	Non-electric demand [kWh/yr]	Source energy [kBtu/yr]
Kitchen dishwasher	1	yes	1	130	0	1401.6
Laundry - washer	1	yes	0.3	17.6	4.4	237.1
Laundry - dryer	1	yes	1.9	192.5	0	2075.6
Energy consumed by evaporation	0	yes	3.1	0	27.7	298.2
Kitchen fridge/freeze combo	1	yes	1.5	547.5	0	5902.8
Kitchen cooktop	1	yes	0.2	200	0	2156.3
PHIUS+ 2015 Misc electric loads	1	yes	1,105.8	1105.8	0	11921.5
PHIUS+ 2015 Interior lighting	1	yes	394.8	394.8	0	4256.6
PHIUS+ 2015 Exterior lighting	1	no	20	20	0	215.7
Σ	8			2608.2	32.1	28465.3



INTERNAL HEAT GAINS

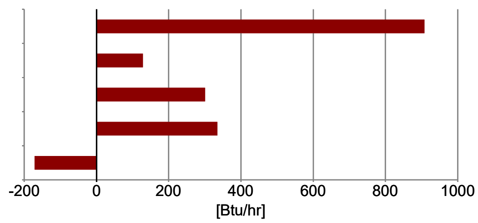
Heating season

Electricity total:	**908.1**	Btu/hr
Auxiliary electricity:	**74.7**	Btu/hr
People:	**300.3**	Btu/hr
Cold water:	**-29.9**	Btu/hr
Evaporation:	**-170.6**	Btu/hr
Σ:	**1,082.6**	Btu/hr
Specific internal heat gains:	**1.2**	Btu/hr ft²



Cooling season

Electricity total:	**908.1**	Btu/hr
Auxiliary electricity:	**128.8**	Btu/hr
People:	**300.3**	Btu/hr
Cold and hot water:	**335**	Btu/hr
Evaporation:	**-170.6**	Btu/hr
Σ:	**1,082.6**	Btu/hr
Specific internal heat gains:	**1.2**	Btu/hr ft²



DHW AND DISTRIBUTION

DHW consumption per person per day:	**6.6**	gal/Person/day
Average cold water temperature supply:	**51.7**	°F
Useful heat DHW:	**3,593.7**	kBtu/yr
Specific useful heat DHW:	**3,934.8**	Btu/ft²yr
Total heat losses of the DHW system:	**1,503**	kBtu/yr
Specific losses of the DHW system:	**1,645.7**	Btu/ft²yr
Performance ratio DHW distribution system and storage:	**1.4**	
Utilization ratio DHW distribution system and storage:	**0.7**	
Total heat demand of DHW system:	**5,096.7**	kBtu/yr
Total specific heat demand of DHW system:	**5,580.5**	Btu/ft²yr
Total heat losses of the hydronic heating distribution:	**0**	kBtu/yr
Specific losses of the hydronic heating distribution:	**0**	Btu/ft²yr
Performance ratio of heat distribution:	**100**	%

Region	Length [ft]	Annual heat loss [kBtu/yr]
Hydronic heating distribution pipes		
Σ	0	0
DHW circulation pipes		
In conditioned space	0	0
Σ	0	0
Individual pipes		
In conditioned space	130	689.1
Σ	130	689.1
Water storage		
Device 3 (Water storage: DHW): Solar Hot Water Tank		813.9
Σ		813.9

APPENDIX C: COMPETITION ENERGY MODELING SPREADSHEET

Contest Event Key			
Task	**Units**	**kWh/unit**	**Source**
Refrigerator/Freezer	Hours	0.07	Energy Star Rating
Washer	Loads	0.28	
Dryer	Loads	0.53	
Dishwasher	Loads	1.05	
HVAC	Hours	0.25	High estimate of 6 kWh/day
Lighting	Hours	0.40	Nominal wattage of all light fixtures, derated by 50%
Home Electronics	Hours	0.14	50W latptop, 85W TV
Hot Water	Draws	0.93	55F rise, COP of 2.5
Commuting	Trips	7.25	BMW i3 Rated Fuel Economy
Cooking	Tasks	1.66	Thermodynamics
Game Night	Event	1.00	Safety Factor
Dinner Party	Events	5.00	Estimate
MISC Mechanical	Day	1.00	Safety Factor

Energy Schedule											
Contest Day	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**SUM**	**Energy (kWh)**
Refrigerator/Freezer[1]	16	24	24	24	24	24	24	24	10.5	**194.5**	12.88
Washer	0	1	1	1	0	1	1	0	0	**5**	1.39
Dryer	0	1	1	1	0	1	1	0	0	**5**	2.63
HVAC[2]	6.5	17	17	17	18.5	24	24	17	10.5	**151.5**	37.88
Lighting	3	5	5	4	3	3	5	2	0	**30**	12.00
Home Electronics	0	3	3	3	0	5	6	3	2	**25**	3.38
Hot Water	0	2	2	0	0	3	3	2	2	**14**	13.02
Commuting	0	0	1	1	0	1	1	1	0	**5**	36.25
Cooking	0	0	1	1	0	1	2	0	1	**6**	9.95
Game Night	1	0	0	0	0	0	0	0	0	**1**	1.00
Dinner Party	0	0	0	0	0	1	1	0	0	**2**	10.00
MISC Mechanical	1	1	1	1	1	1	1	1	1	**9**	9.00
Energy:	5.88	11.91	20.82	18.56	8.41	27.97	30.56	17.15	8.11	**TOTAL:**	140.37
										kWh/Day:	15.60

NOTES

[1]Will run even when not measured.

[2]Increased time for precooling/preheating

APPENDIX D: R-VALUE CALCULATIONS

Walls

Material	Thickness (in)	Nominal R-Value	Effective R-Value
7/16" LP SmartSide	7/16"	0.51	0.51
7/16" OSB	7/16"	0.51	0.51
5.5" PU Foam	5-1/2"	38.5	38.5
7/16" OSB	7/16"	0.51	0.51
1/2" Drywall	1/2"	0.45	0.45
	SUM:	**40.48**	**40.48**

Roof

Material	Thickness (in)	Nominal R-Value	Effective R-Value	
Asphalt Shingles	n/a	0.44	0.44	
7/16" OSB	7/16"	0.51	0.51	
5.5" PU Foam	5.5"	38.5	38.5	
7/16" OSB	7/16"	0.51	0.51	
Air Gap	1/4"	0.3	0.3	
5-1/2" Mineral Wool Insulation (R-23)	6"	23	23 (see below)	
Thermal Bridging: 6" Steel Studs @ 24" O.C.	6"		16.1	From IECC 2015 Table R402.2.6
5/8" Drywall	5/8"	0.45	0.45	
	SUM:	**63.71**	**56.81**	

Floor

Material	Thickness (in)	Nominal R-Value	Effective R-Value
1/2" CDX Plywood	1/2"	0.62	0.62
7.25" Mineral Wool Insulation	7-1/4"	30	
Thermal Bridging: TJI 210 (7/16" OSB Web @16" OC)	9.5"		25
Air Space	1/2"	0.6	0.6
3/4" Advantech Subfloor	3/4"	1.19	1.19
5/8" Engineered Hardwood Flooring	5/8"	0.625	0.625
	SUM:	**33.035**	**28.035**

Technical Data

Foam Characteristics

Compressive Strength	ASTM D-1624-00	35 psi
Compressive Modulus	ASTM D-1624-00	790 psi
Density	ASTM D-1622-98	2.4-2.5 pcf
Dimensional Stability	ASTM D-2126-99	Excellent
Flammability – Smoke Generation	ASTM E-84-01	<400
Flammability – Flame Spread	ASTM E-84-01	<25
Foam Core Fire Rating	*** Integrity	Class 1
Linear Coefficient of Thermal Expansion	ASTM D696-98	-40°F to +240°F
Closed Cell Content by Air Pycnometer	ASTM D-2856-87	>96%
Shear Strength	ASTM C-273-61 (1988)	28 psi
Shear Modulus	ASTM C-273-61 (1988)	325 psi
Resistance to Solvent	ASTM D-543-95 (2001)	Excellent
Resistance to Mold/Mildew	ASTM D-543-95 (2001)	Excellent
Thermal Conductivity	ASTM C-518-91	K Factor 0.14 (BTU-in/ft²hr°F)
Thermal Conductivity (aged @ temp)	ASTM C-518-91	R value 7 per inch @ 55°F
Tensile Strength	ASTM D-1623-78 (1995)	58 psi
Tensile Modulus	ASTM D-1623-78 (1995)	325 psi
Water Absorption	ASTM D-2842-01	2.4%
Vapor Permeability	ASTM D-2842-01	2 perm/in

*** Polyurethane foam is a "thermo-set" plastic. Melting does NOT occur.

APPENDIX F: WINDOW AND DOOR SCHEDULE

Window Schedule

Type	Count	Egress	Description	Manufacturer	Model	Frame Type	Exterior Color	Interior Color	Frame Width	Frame Height	Rough Width	Rough Height	Jambs	Glazing Type	Glass SHGC	Unit U-Value
W1	1	No	Window into the Garage	Marvin	Clad Rectangle Direct Glaze	-	Ebony Clad	Espresso Stained Pine	40"	47-1/8"	41"	47-5/8"	7"	Insulated	0.64	0.46
W2	1	Yes	Window into the Convertible Room	Marvin	Clad Ultimate French Casement	CUFCA4848 E	Ebony Clad	Espresso Stained Pine	48"	47-1/8"	49"	47-5/8"	7"	Tri-Pane	0.39	0.21
W3	1	No	Window in the Kitchen Area	Marvin	Clad Ultimate French Casement	CUCA4848	Ebony Clad	Painted White Pine	48"	47-1/8"	49"	47-5/8"	7"	Tri-Pane	0.39	0.21
W4	1	No	Window in the Master Bedroom (above bed)	Marvin	Clad Ultimate Awning	CUAWN4824	Ebony Clad	Espresso Stained Pine	48"	23-1/8"	49"	23-5/8"	7"	Tri-Pane	0.39	0.21
W5	1	Yes	Window #2 in the Master Bedroom	Marvin	Clad Ultimate Casement	CUAWN3648	Ebony Clad	Espresso Stained Pine	36"	47-1/8"	37"	47-5/8"	7"	Tri-Pane	0.39	0.21
W6	1	No	Window in the Master Bathroom	Marvin	Clad Ultimate Awning	CUAWN4824	Ebony Clad	Espresso Stained Pine	48"	23-1/8"	49"	23-5/8"	7"	Tri-Pane	0.39	0.21
W7	4	No	Clearstory WIndows	Marvin	Clad Ultimate Push Out Awning	CUPAWN4818	Ebony Clad	Espresso Stained Pine	48"	17-1/8"	49"	17-5/8"	7"	Tri-Pane	0.39	0.23
W8	1	No	Window into the Entrance Vestibule	Marvin	Clad Ultimate Picture Casement	CUCVP 6472 T	Ebony Clad	Espresso Stained Pine	64"	71-1/8"	65"	71-5/8"	7"	Insulated	0.32	0.28

(continued)

Type	Gas	Glass Coating	Operation	Handle Finish	Comments	CPD #:
W1	Air	None	None	/	Tempered	MAR-N-419-05027-00025
W2	Krypton-Argon	Low E1/Low E1	French Casement	Oil Rubbed Bronze		MAR-N-342-14094-00001
W3	Krypton-Argon	Low E1/Low E1	Double Casement	Matte White		MAR-N-342-14094-00001
W4	Krypton-Argon	Low E1/Low E1	None	/	Tempered	MAR-N-342-14094-00001
W5	Krypton-Argon	Low E1/Low E1	Casement	Matte Black		MAR-N-342-14094-00001
W6	Krypton-Argon	Low E1/Low E1	Roto Awning	Matte Black	Tempered	MAR-N-342-14094-00001
W7	Krypton-Argon	Low E1/Low E1	Roto Awning	Matte Black	Tempered	MAR-N-360-05552-00001
W8	Argon	Low E2	Venting	Oil Rubbed Bronze	Tempered	MAR-N-378-01185-00001

Door Schedule

Type Mark	Description	Count	Manufacturer	Model	Frame Type	Exterior Color	Interior Color	Frame Width	Frame Height	Rough Width	Rough Height	Jambs	Glazing Type	SHGC	(U) Value (btu/hr-ft^2-F)	Gas	Coating	Operation
D1	Entry Vestibule Door Plus Sidelite	1	Therma-Tru	FCM1000/ FCM1210 1SL-LE	wood	Walnut Stain	Walnut Stain	51-5/8"	81"	51-7/8"	81-1/2"	7"	Low-E	/	0.14	Air	Low E	RH Outswing
D2	Door into Garage from the Entrance Vestibule	1	Therma-Tru	FMF100	wood	Walnut Stain	Painted White	37-5/8"	85"	38-3/8"	85-1/2"	7"	/	/	0.14			LH Inswing
D3	Door Entering into Living Space from Entrance Vestibule	1	Therma-Tru	FCM1000	wood	Walnut Stain	Walnut Stain	37-5/8"	85"	38-3/8"	85-1/2"	7-3/8"	/	/	0.14			Right-Handed
D4	Sliding Door From Living Spce to South Deck/Enclosed Patio	1	Marvin	Clad Ultimate Lift and Slide Door Performance Sill	Stacked Contemporary (OX-XO)	Ebony Clad	Espresso Stained Pine	176"	81-1/2"	177"	82"	7"	Insulated, Tempered	0.32	0.29	Argon	Low E2	Sliding (OX-XO)
D5	Sliding Door From Living Spce to North Deck	1	Marvin	French Outswing Door	60R68	Ebony Clad	Espresso Stained Pine	71"	82"	72"	82-1/2"	7"	Insulated, Tempered	0.32	0.29	Argon	Low E2	Outswing
D6	Door Entering the Master Bedroom from South Deck	1	Therma-Tru	FCM1286	wood	Walnut Stain	Walnut Stain	37-5/8"	81"	38-3/8"	82-1/4"	7"	Low-E	0.17	0.28	Air	Low E	LH Outswing
D7	Door From South Deck into Sotuh Enclosed Patio	2	POOL&SPA ENCLOSURES	Corso Ultima	/			/	/	/	/			0.83 (Roof) 0.81 (Walls)	0.67 (Roof) 1.0 (Walls)			Sliding

(continued)

Type Mark	Description	Count	Manufacturer	Model	Frame Type	Exterior Color	Interior Color	Frame Width	Frame Height	Rough Width	Rough Height	Jambs	Glazing Type	SHGC	(U) Value (btu/hr-ft^2-F)	Gas	Coating	Operation
D8	Door into Mechanical Shed	1	Therma-Tru	S104	wood	White	White	31-5/8"	82"	32-3/8"	82-1/2"	7"	Simple Clear Glass	0.19	0.27	Air	/	RH Inswing
D9	Garage Door for Car	1	-	/	/			9'	7'	/	/			/	/			Roll Up
D10	Barn Door From Convertable Spce to Living Area	1	TruStile	/	/			5'	6'8"	/	/			/	/			Sliding/Barn
D11A	Barn Door into Masterbath	1	TruStile	/	/			3'	6'8"	/	/			/	/			Sliding/Barn
D11B	Barn Door into Guest Bath	1	TruStile	/	/			/	/	/	/			/	/			Sliding/Barn
D12	Door from Living Space into Master Bedroom	1	TruStile	/	/			3'	6'8"	/	/			/	/			Left-Handed
D13	Door to Convertible Room Closet	1	TruStile	/	/			/	/	/	/			/	/			LH Outwsin
D14	Door to Master BR Closet	1	TruStile	/	/			/	/	/	/			/	/			Bypass
D15	Door to Mechanical Closet	1	TruStile	/	/			/	/	/	/			/	/			Bifold

(continued)

Type Mark	Door Type	Handle Finish	Comments	CPD #:
D1	Exterior	Metal		
D2	Exterior	Metal	20-Minute Fire Rated with Spring Hinge Closer	
D3	Exterior	Metal		
D4	Exterior	Satin Nickel	MAR-N-404-00119-00(	
D5	Exterior	Satin Nickel	MAR-N-263-02699-00(	
D6	Exterior	Metal		
D7	Exterior	Metal		

(continued)

Type Mark	Door Type	Handle Finish	Comments	CPD #:
D8	Exterior	Metal		
D9	Exterior	Metal		
D10	Interior	Metal		
D11A	Interior	Metal		
D11B	Interior	Metal		
D12	Interior	Metal		
D13	Interior	Metal		
D14	Interior	Metal		
D15	Interior	Metal		

System Checksums

By HILL GROUP

CENTRAL UNIT — **Single Zone**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 16; Outside Air: OADB/WB/HR: 92 / 75 / 108

CLG Space Peak — Mo/Hr: Sum of; OADB: Peaks

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	942	0	942	6	942	7
Glass Solar	3,849	0	3,849	25	3,849	28
Glass/Door Cond	714	0	714	5	714	5
Wall Cond	1,009	0	1,009	7	1,009	7
Partition/Door	0		0	0	0	0
Floor	149		149	1	149	1
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	6,662	0	6,662	44	6,662	49
Internal Loads						
Lights	2,381	43	2,424	16	2,381	18
People	4,000	0	4,000	26	2,470	18
Misc	2,045	0	2,045	14	2,045	15
Sub Total ==>	8,426	43	8,469	56	6,896	51
Ceiling Load	0	0	0	0	0	0
Ventilation Load	0	0	0	0	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		0	0	0		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	15,088	43	15,131	100.00	13,558	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: -10

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	-1,651	-1,651	16.14
Glass Solar	0	0	0.00
Glass/Door Cond	-3,804	-3,804	37.19
Wall Cond	-2,767	-2,767	27.04
Partition/Door	0	0	0.00
Floor	-2,008	-2,008	19.63
Adjacent Floor	0	0	0
Infiltration	0	0	0.00
Sub Total ==>	-10,230	-10,230	100.00
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	0	0	0.00
Ventilation Load	0	0	0.00
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		0	0.00
OA Preheat Diff.		0	0.00
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-10,230	-10,230	100.00

TEMPERATURES

	Cooling	Heating
SADB	56.0	84.3
Ra Plenum	75.0	70.0
Return	75.1	70.0
Ret/OA	75.1	70.0
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	655	655
Terminal	655	655
Main Fan	655	655
Sec Fan	0	0
Nom Vent	0	0
AHU Vent	0	0
Infil	0	0
MinStop/Rh	0	0
Return	655	655
Exhaust	0	0
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	0.0	0.0
cfm/ft²	0.76	0.76
cfm/ton	519.51	
ft²/ton	686.40	
Btu/hr·ft²	17.48	-11.82
No. People	10	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	1.3	15.1	13.6	655	75.1	61.2	60.5	56.0	53.1	57.1
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.3	15.1								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	865		
Part	0		
Int Door	0		
ExFlr	865		
Roof	1,032	0	0
Wall	1,630	247	15
Ext Door	79	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-10.2	655	70.0	84.3
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-10.2			

Project Name: HBN- House by Northwestern
Dataset Name: HBN - SD2017 - GBXML.TRC

TRACE® 700 v6.3.2 calculated at 03:38 PM on 10/18/2016
Alternative - 1 System Checksums Report Page 1 of 1

APPENDIX H: SPEC SHEET FOR CX34

The World's Most Efficient Chiller Heat Pump

Ultra-Efficient
CX34 Chiller Heat Pump

2 Tons Cooling / 3 Tons heating
IPLV Cooling 26,615 BTU COP 6.75 EER 23.02
NPLV Cooling 30,049 BTU COP 9.0 EER 30.72
Heating 33,813 BTU COP 3.92

AHRI CERTIFIED

Multiple IDUs - Up to 8 Indoor Units Per CX34

Ultra High Efficiency Heat Pump Chiller

The CX34 obtains it's ultra high efficiency using existing technologies in a new way. For example, we use a DC Inverter compressor and a DC Inverter water pump (both are variable speed) controlled together with a DC inverter fan motor to achieve the best possible balance of water flow rate, compressor speed, and energy use.

A special control algorithm looks at the temperature delta between the entering and exiting water temperatures of the chiller, and also compares the exiting water temperature to the system settings. The controller constantly adjusts the pump and compressor speeds independently of each other to maintain the needed capacity at the lowest possible power draw, usually avoiding the need for a buffer tank. There is not a more efficient air source heat pump chiller made anywhere by anyone.

Dynamic Humidity Control (DHC)

The Chiltrix Psychrologix ™ controller offers DHC (Dynamic Humidity Control) to maximize comfort and performance and allow the unit to operate well above its published ratings at times when humidity allows. The controller provides dynamic loop/coil temperature adjustment among other features.

The CX34 system capacity is fully dynamic and can operate between 25% and 100% of its rated capacity, as needed, and matches its actual capacity to the instantaneous heating or cooling load in real time. This means the system is always the right size for changing conditions and is never oversized and avoids the on/off cycling of traditional systems.

Save More w/ DC Inverter Fan Motors

All of the thin-line (5.1" thin) wall, floor and ceiling fan coil units use high efficiency and nearly silent DC Inverter fan motors, designed for 115v 50/60Hz power. 220v 50/60Hz standard FCUs are available for export customers.

Geothermal Performance

There is no Energy Star program for air-cooled chillers. However, the Chiltrix air-cooled chiller exceeds the Energy Star EER requirements for geothermal water-to-water systems.

Server Room Cooling

Chiltrix offers an optional Free Cooling add-on which allows up to EER 141+ & COP 41+ cooling performance during winter at low ambient temperatures. Chiltrix chillers are also available in a N+1 redundant configuration.

Solar Ready

Perfect for solar PV operation with super low power draw and a 2 amp soft start that's easy on inverters and batteries. Also integrates directly with solar thermal hydronic heating & solar water heating systems.

Radiant, Boiler & Hydronic Integration

Can serve as low-cost primary heat when used with an existing boiler heating system. Perfect for radiant floor heating. Dramatically reduces heating costs for users of electric, propane or oil fired boiler systems.

Modular – Stackable

The CX34 can be configured with up to 3 outdoor units to create systems up to 6 Tons Cooling/8.5 Tons Heating

Heating Performance

The CX34 provides heating down to outdoor temperatures as low as -4F (-20C).

AHRI CERTIFIED www.ahridirectory.org
Air-Cooled Chillers
AHRI Standard 550/590

UL 60335-2-40 / CSA 22.2 / SGS

All Specifications Subject To Change

www.chiltrix.com

626174/01

The World's Most Efficient Chiller Heat Pump

Ultra-Efficient
CX34 Chiller Heat Pump

2 Tons Cooling / 3 Tons heating
IPLV Cooling 26,150 BTU COP 6.75 EER 23.02
NPLV Cooling 30,049 BTU COP 9.0 EER 30.7
Heating 33,813 BTU COP 3.92

The CX34 is Stackable up to 3 Systems
Use up to 8 Indoor Units per Outdoor Unit.

UL 6035-2-40 / CSA C22.2 / SGS

Best of Breed Components

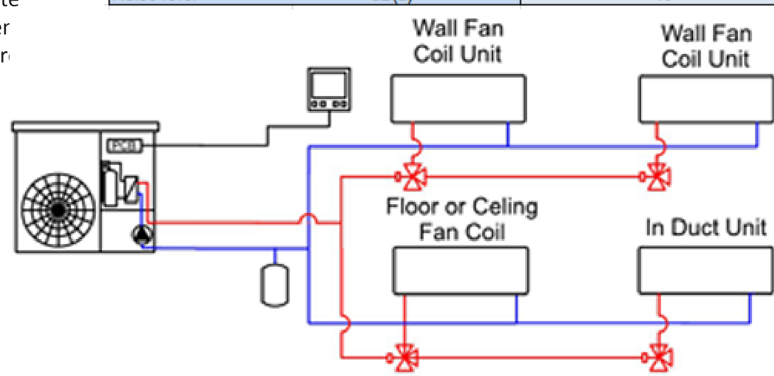
At Chiltrix we used every trick in the book and then some to deliver the highest electrical efficiency possible. And we didn't stop there. The components we use to build our chillers are sourced from the world's top manufacturers and include heat exchangers from Sweden, German pumps, American valves, electronics from Japan, controls from USA, and a compressor from Mitsubishi.

No corner has been cut when it comes to making sure that the parts and materials used to manufacture the CX34 are the best available. Our chiller is designed for performance - to deliver the lowest kW usage per BTU of any chiller heat pump available, and to perform this task for a 20-year service life.

Anti-Corrosion Technology to protect against salt air or air pollution is incorporated into all Chiltrix outdoor units. Includes special coil, sealed compressor and fan motor.

There is no other chiller like the CX34 available on the market at any price. Contact us to learn more about designing a chiller system for your home, commercial location, or server room. We can also help you integrate our system with an existing system, retrofit replacemer or integration with solar or to an existing boiler or hydr heating system.

Model CX34 Per AHRI 550/590	Ambient / LWT (ºF)	Capacity / Input BTU/kW
Heating	at A43/W95	33,813/2.53
	at A17/W95	22,237/2.32
Cooling	Efficiency A95/W44	IPLV EER 23.02
	Efficiency A95/W54	NPLV EER 30.7
Cooling Capacity/Max Power Input(kW)	at A95/W44	26,150 / 2.36
	at A95/W54	30,049 / 2.36
Input Power	Variable (kW)	.364 - 2.36
Max.Current/ Min. Circuit (A)		15/20
Electric supply		208-240V / 50~60HZ
Max.Water Temperature (°C)		55 (131F)
Operating Temperature Range (°C)		-20 ~ 50 (-4F ~ 122F)
Refrigerant Circuit	Refrigerant	R410a
	DC Inverter Compressor(s)	Mitsubishi Scroll - DC Inverter
	Heat Exchanger	Cu/Al Hydrophilic w/ Anti-Corrosion
	Electronic Expansion Valve	Saginomiya Japan
	Condenser Fan Motor	Panasonic DC Fan
	Max Air flow (CFM)	1700
Water Circuit	Heat exchanger	Multistack BPHE
	Inlet / Outlet	1" NPT
	Water Flow - Max	7.6 GPM
	Pump	Wilo DC Variable Speed
	Max/Std. Pressure	115/25 PSI
Unit Dimensions WxHxD (Inch)		43.9 x 38.15 x16.74
Package Dimensions WxHxD (Inch)		46 x 49.25 x 18.5
Net Weight (Lbs.)		232
Gross weight (Lbs.)		254
Noise level dB(a)		49



Up to 8 Indoor Units

You can use up to 8 indoor fan coil units of any type including high-wall (mini-split type), low wall, ceiling, floor standing, etc. You can also use in-duct fan coil units for creating a small central heating & air conditioning system.

The system is also compatible with radiant hydronic heating, or can be connected to a boiler system to provide a low cost primary heating source.

AHRI CERTIFIED www.ahridirectory.org Air-Cooled Chillers AHRI Standard 550/590

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Chiltrix

www.chiltrix.com

All Specifications Subject To Change

AHRI CERTIFIED®
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Certificate of Product Ratings

AHRI Certified Reference Number: 10317769 Date: 5/30/2017 †Status: Active

Product: Air Cooled Chilling Package
Model Designation: CX34
Manufacturer: CHILTRIX INC.
Trade/Brand name: CHILTRIX;LEZETI;SERVCOOL

Rated as follows in accordance with the latest edition of AHRI Standards 550/590 (I-P) and 551/591 (SI) for Water-Chilling Packages using the Vapor Compression Cycle(Air-Cooled) and subject to verification of rating accuracy by AHRI-sponsored, independent, third party testing:

Refrigerant Used:	R410A
Compressor Designation:	TNB220FFEMC
Compressor Type:	Scroll
Catalog Name:	ChiltrixCX
Catalog Issue Date or Code:	V1.0
Country Of Origin:	France
Hertz:	60

† Models with an 'Active' status are those that are currently in production. Models with a 'Discontinued' status are those that the manufacturer has elected to stop producing, yet stock is still available. Models with an 'Obsolete' status are those that the manufacturer is required to stop manufacturing due to an AHRI certification program test failure.

* Ratings followed by an asterisk (*) indicate a voluntary rerate of previously published data, unless accompanied with a WAS, which indicates an involuntary rerate.

CERTIFICATE VERIFICATION
The information for the model cited on this certificate can be verified at www.ahridirectory.org, click on "Verify Certificate" link and enter the AHRI Certified Reference Number and the date on which the certificate was issued, which is listed above, and the Certificate No., which is listed at bottom right.

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we make life better™

CERTIFICATE NO.: 131406441091006389

Chiltrix Chiller With Psychrologix™ Controller

Ultra-High Efficiency Chiller Heat Pump With Dynamic Humidity Control

PATENT PENDING

Introduction

The Chiltrix chillers employ a unique design utilizing a special capacity control approach coupled with variable speed compressors, variable speed pumps, and variable speed fans, further combined with dynamically variable control parameters that continuously adjust to meet operating conditions and considerations. The Chiltrix chillers match capacity to changing cooling loads precisely enough that often buffer tanks are not needed. A dynamic psychrometric controller manages humidity, prevents over-dehumidification, and saves energy by operating the chiller in the most efficient possible manner at all times. The new CX34 is extraordinarily efficient and offers a record-setting official AHRI IPLV rating of EER 23. With DHC active, EER (NPLV) is as high as EER 30.7 or above.

Chillers vs. Air Conditioners

First, a word about chillers. Chillers use a compressor and refrigerant to provide cooling. A chiller is defined as an air conditioning system that cools water (or a glycol-water mix). The cold water is circulated through a water distribution "loop" and ultimately through one or more indoor fan coil units to cool indoor air before returning the water back to the chiller. The Chiltrix system is a heat pump chiller. A common misperception is that chillers consume water, however, that is not the case with Chiltrix. Others may think that chillers require a cooling tower – however the Chiltrix chillers are air-cooled and do not use a cooling tower. Pumping water for cooling may seem old-fashioned, but it is more efficient than pumping refrigerant, for one reason, because the water can be pumped at a much lower pressure. This is different from a standard air conditioner because a regular air conditioner circulates a high pressure refrigerant such as Freon through a distribution loop. Basic physics tells us that it takes less energy to pump a fluid at lower pressure. Another thing to consider is that water is better, pound for pound, than Freon and other refrigerants at carrying heat (except for ammonia, which is too dangerous for most applications). In a regular air conditioner, the compressor not only creates the cooling, it also must power the distribution circuit by pumping high pressure refrigerant through the entire loop. In a chiller, a separate low wattage pump is used for pumping low pressure water through the loop and the compressor is only used for cooling. For these and other reasons, chillers are inherently more efficient than regular air conditioners.

Dehumidification

A side benefit of all standard air conditioning systems is dehumidification (humidity removal). Dehumidification occurs when a fan blows air across cooling coils to condition an indoor space, when the coils operate at a temperature below the dew point of the air. This is generally the case for the coils of an air conditioner or chiller indoor air handler. Dehumidification is an excellent benefit, when needed, as it can protect against mold, dust mites, fungus, and corrosion of mechanical systems. Lower humidity can also make warm air feel cooler than it really is, this effect is sometimes referred to as "feels like temperature" or "apparent temperature". However, over-dehumidification can also cause problems and unnecessary dehumidification wastes a large amount of electrical energy.

Dry Climate Conditions

There are often cases where too much humidity can be removed from the air by air conditioners resulting in over-dehumidification. For example, you may see air conditioning users in dry climate conditions operating a humidifier to add humidity back into the air because the air conditioning system has over-dehumidified the air. Overly dry air can result in dry skin, irritated sinuses and throat, nosebleeds, and itchy eyes. Repeated exposure to low humidity can dry out and inflame respiratory tract mucous membranes which can increase the risk of colds or flu. Static electricity is an annoyance that is increased when humidity is low. For human comfort and health it is important to have a proper level of indoor humidity – not too high or too low. The recommended humidity levels for human health and comfort are generally in the range of 50-65% relative humidity (Per ASHRAE 62.1-2003).

Computer / Server Rooms

An area where we nearly always see humidity lower than recommended is in computer or server room cooling applications. In this application, air conditioners run non-stop around the clock to reject heat from electronic equipment. Ideally the room is a mostly closed environment to protect equipment from contamination, therefore, the same air is cooled over and over again. All or nearly all of the cooling load in a computer server room is generated as dry heat, or more properly, "sensible heat" because it is derived from the electrical resistance of processors, circuit boards, power supplies, etc. Unlike latent heat (humid heat), sensible heat sources do not add humidity to the air. The continuous operation of a server room air conditioner repeatedly cooling the same air often lowers the humidity much further than is needed or desirable which is very wasteful of energy. And when humidity is too low, the risk of potentially harmful static discharge (up to 10 kV/cm) is dramatically increased.

Humidity Control in Residential Applications

For the most part, dehumidification in small office/home applications is haphazard. The air conditioning system is controlled by a thermostat which measures sensible temperature to decide when to start and stop, providing a hit or miss level of dehumidification. Dehumidification generally occurs whenever the unit is running. The humidity therefore rises and falls randomly, is not monitored or controlled, and is rarely at the most comfortable or most energy efficient point. For most users, any accurate control of humidity for comfort or health purposes would have to be provided by purchasing, installing, and operating a separate humidifier and/or dehumidifier system that essentially fights with the air conditioner and wastes energy.

Wasted Capacity

A large amount of a systems total capacity can be used in the process of dehumidification or "latent heat removal". Unnecessary latent heat removal is wasteful of net system capacity because each pint (lb.) of water removed from a room adds more than 1,000 BTU to the cooling load of the room. Preventing unnecessary dehumidification can increase the net effective cooling capacity of an air conditioner. A system controlled such as Chiltrix that only dehumidifies when, and to the proper extent that dehumidification is needed, can produce much more total cooling with the same compressor and same energy usage.

Wasted Energy

Generally speaking, the rate of dehumidification is a factor of the temperature difference (ΔT) between the dew point of the indoor air and the coil temperature of the air conditioner indoor unit. The colder the coil in relationship to the dew point, the more dehumidification is performed. In a standard air conditioner using refrigerant such as R410a, R22, "Freon" etc., the system has little or no ability to modulate the coil temperature, which is very cold and generally well below the dew point. Therefore, a standard air conditioner is nearly always performing or attempting to perform dehumidification regardless of whether or not dehumidification is needed.

A system such as the Chiltrix chiller with Dynamic Humidity Control activated can modulate the temperature of the cooling coils such that the coils are at the proper ΔT below the dew point when dehumidification is needed but can operate above the dew point when dehumidification is not needed. This feature can prevent the disadvantage of wasted energy or discomfort due to over-dehumidification and maintain the correct level of humidity with less energy usage.

What is IPLV?

IPLV means "integrated part load value", a concept similar to SEER. IPLV is an official AHRI standardized testing and rating methodology which provides an average EER rating under real-world conditions. "Part load" refers to times when the system is larger than it needs to be at that moment, which is nearly all of the time for a properly sized system, since a system must be sized for the hottest possible day of the year which is the actual condition only about 1% of the time. NPLV is the same concept, but with non-standard operating conditions. IPLV and NPLV are to chillers, what SEER is to standard air conditioners.

Carnot Analysis / Energy Efficiency (EER)

EER is the energy efficiency ratio, a measure of how much energy is needed to perform a BTU of cooling. In a chiller system, the thermodynamic process is one of removing heat; a chiller in cooling mode is essentially a machine that removes heat from water. An elementary Carnot analysis (or even simple common sense) shows that the warmer the water, the less energy or work is needed to remove heat from it, therefore operating a chiller with a warmer loop will unquestionably increase the EER. As an example of this, our newest Chiltrix (CX34) chiller tested at AHRI 550/590 conditions achieves an IPLV EER of 23 at 44F LWT, and an NPLV EER of 30.7 at 55F LWT, in this case, an EER increase of 33%. The CX34 can operate above NPLV, at times, with average EER rising up to 50% above IPLV.

By running the loop/coils no colder than needed within a range that allows humidity targets to be satisfied, the dynamically controlled system will have a higher average EER using less electrical energy per BTU of cooling. Part load performance numbers show a 33-50% difference. The Chiltrix system loop & coil temperature target can dynamically adjust itself from ~40°F to 62°F, the system will run no cooler than needed, while at the same time, automatically modulate its loop temperature downward when necessary to satisfy dehumidification requirements.

Dynamic Humidity Control (DHC)

The Chiltrix chiller with DHC has the ability to dynamically adjust the loop water temperature, and thus modulate the coil temperature in response to indoor relative humidity and dew point conditions. A control algorithm reads input from indoor sensors and adjusts the temperature of the water/coils such that the water loop and coil temperatures can be equal to, just above, well above, just below, or well below, the dew point, resulting in controllable dehumidification and controllable humidity. This allows the system to operate the coils above the dew point when the humidity is at an acceptable level (no dehumidification performed) and drop below the dew point when dehumidification is needed. The Chiltrix system is designed to operate the loop at the warmest possible temperature that will allow proper cooling of the space and allow the user-defined humidity levels to be maintained.

How the Chiltrix Chiller Works with DHC

The Chiltrix chiller can react very rapidly to humidity condition changes. The Chiltrix chiller uses a variable speed DC Inverter compressor, and a variable speed DC Inverter water pump, and DC inverter fan. By controlling the compressor speed, the system regulates the leaving/exit loop temperature. By controlling the speed of the pump the Chiltrix chiller maintains a constant ΔT between its entering and leaving temperature and provides the correct flow rate to match the capacity requirements. Controlling the pump and compressor together in this manner, the variable capacity Chiltrix output is always matched to the current cooling load. Because the Chiltrix chiller can dynamically match the load, there is often no need for a buffer tank. Because there is no buffer tank, the Chiltrix chiller can rapidly execute commands received from the DHC to adjust the loop temperature in real time for purposes of accurate and responsive humidity control.

Chiltrix Psychrometric Controls

As mentioned, the control of the Chiltrix system is such that a constant ΔT is maintained between entering water temperature (EWT) and leaving water temperature (LWT) and the compressor speed is dynamically managed to maintain a LWT set point. In this manner, the capacity is matched in real-time to the cooling or heating load. For example, at a baseline operating condition in cooling mode the system may have parameters such as EWT 54F, LWT 44F (ΔT of 10F), and a 2.4 GPM flow, meaning that the capacity and load are both 12,000 BTU. An increase in EWT (Increase in ΔT) would indicate an increased load. For example, a change in sensed conditions to ΔT 13F would indicate an increase in cooling load from 12,000 BTU to 15,600 BTU. The Chiltrix system would dynamically respond by increasing compressor and pump speed to match the new load, i.e., the system would produce a higher compressor speed to match the new BTU requirement and flow would increase to 3.12 GPM producing a return to 10F ΔT at the new higher compressor speed. The new conditions would then be EWT 54, LWT44, and based on this, 3.12x10x500=15,600 BTU. In this manner, the chiller capacity is always directly targeted to the load and flow is maintained at 2.4 GPM/ton.

The controls system dynamically and continuously varies the LWT target based on conditions, to control dehumidification and to operate the chiller at the highest possible Carnot efficiency. For example, if indoor sensors indicate that no dehumidification is needed, the LWT target can be dynamically adjusted upwards to produce a far more efficient operating state. However, if a door opens and humid air enters the conditioned space, and humidity rises above its set point, the system will lower the LWT below the dew point to an extent and until such time as humidity is under control. Then, as conditions allow, it will recover back to the most efficient state. As mentioned, the Chiltrix chiller EER is substantially higher when operating at NPLV conditions (55F LWT) as opposed to IPLV conditions (44 LWT).

An often-missed aspect of indoor humidity is that indoor humidity is “event based”. In other words, humidity does not increase on its own or enter the indoor space through walls, or increase due to solar gain or from the use of electronics or lighting. Indoor humidity increases only when some event occurs, such as an exterior door opening that allows humid outdoor air to enter the space, or someone taking a hot shower, etc. Once humidity rises to a user-defined level, the Chiltrix DHC controller reacts to it by changing its operating parameters to enable or increase dehumidification. After the humidity has been handled, the Chiltrix unit will move back to its more efficient operating state where it will remain until dehumidification is needed again.

Vacation/Dry Mode

Residential users may also wish to set the Chiltrix chiller system in “vacation mode” at appropriate times. In vacation mode the system will ignore indoor temperature and focus only on keeping humidity under a preset level saving a large amount of electrical energy while the home is unoccupied, yet the home is still being protected from humidity and moisture damage. This mode of operation may also be suitable for climate controlled storage such as needed for textiles, documents, etc. A wintertime vacation mode can prevent freezing and save energy by operating the heating loop at a far lower temperature than would be needed for human health or comfort.

Geothermal Comparison

The Chiltrix chiller is air-cooled, but can be compared to many water-to-water (geothermal) units as far as efficiency. Of course a price comparison would show the Chiltrix unit to have a far lower installed cost. While Energy Star currently has no program for air-to-water chillers, it's interesting to note that the Chiltrix air cooled chiller exceeds the efficiency (EER) requirements that are needed for a variable speed geothermal unit to earn an Energy Star label.

Hardware Considerations

A basic thermodynamic analysis explains that running a warmer loop during cooling mode requires indoor coil equipment to be configured such that it has enough sensible capacity at times when the loop is operating at warmer temperatures. Simply put, the cooling capacity of an indoor fan coil unit is a function of air flow, coil surface area, and ΔT (between the air and the coil). If due to a warmer coil the ΔT is to be lower, then fan speed and/or coil surface area must be increased to compensate. Chiltrix chiller system design is such that indoor fan coil units are sized a little larger than they would need to be for strictly standard operating conditions, they are sized to achieve the needed sensible cooling capacity while supporting a wide range of loop water temperatures at or above standard conditions. In the Chiltrix chiller system design, indoor equipment is sized to accommodate sensible cooling loads at 55 LWT or above. While this approach may at times slightly increase indoor fan energy, a far larger reduction in compressor energy makes this an exceptionally favorable trade-off.

Summary

The Chiltrix use of capacity matching controls and variable speed components, combined with continuously variable operating parameters, offers an unprecedented level of cooling energy savings. The system design maximizes part load energy efficiency and saves additional energy by controlling the energy expended on latent heat removal. The system prevents over-dehumidification. The Chiltrix chiller is, without DHC, already more efficient than any other system in its class. And with DHC enabled, it further lowers energy costs and gains up to 50% additional EER increase. The Chiltrix chiller is perfect for a wide variety of applications including homes and offices in climates with high humidity, low humidity, frequent humidity swings, as well as any applications with variable sensible and latent cooling loads such as equipment cooling, structures with variable occupancy or usage, storage facilities, etc.

Editor's Note-

This document mainly describes operation of the Chiltrix chiller in cooling mode, however, further Carnot analysis easily explains that heating mode energy efficiency is also significantly improved by use of the Chiltrix dynamic capacity matching, variable speed technology, and by taking advantage a more efficient heating LWT parameters made possible by the larger indoor equipment.

Appendix 1.
DEW POINT & HUMIDITY ANALYSIS

TEMP (°F)	RH%	DP (Dew Point)(°F)
80	60	65
80	55	62
80	50	60
80	45	57
80	40	53
78	60	63
78	55	61
78	50	58
78	45	55
78	40	52
76	60	61
76	55	58
76	50	56
76	45	53
76	40	50
74	60	59
74	55	57
74	50	54
74	45	51
74	40	48
72	60	57
72	55	55
72	50	52
72	45	49
72	40	46
70	60	55
70	55	53
70	50	50
70	45	47
70	40	44

The Chiltrix indoor units increase or decrease their fan speed (CFM) to control temperature based on user thermostat settings. In certain applications, the chiller controller also Controls indoor fan speed.

The Chiltrix DHC function monitors indoor humidity and adjusts the indoor unit coil temperature to keep RH% within the user defined allowable range by regulating the loop temperature.

Dehumidification occurs when the coil temperature is below the DP. No dehumidification occurs when the coil temperature is above the DP. When operating below the DP, the rate of dehumidification increases with increased ΔT.

For example, if humidity begins to rise slowly, the DHC controller may lower the system temperature a few °F below the DP. If RH continues to rise, or rises rapidly, the DHC may reduce the coil temperatures to an even lower setting.

As humidity stabilizes within the desired RH range, the DHC will slowly raise the coil temperatures to the highest temperature that allows RH targets to be maintained.

It is critical to maintain proper humidity levels.

Operating the system/coil temperatures as warm as possible, while maintaining RF% targets, allows the system to run at its highest level of total electrical efficiency.

For computer/server rooms: The Class A-1 ASHRAE recommended maximum temperature is 80°F with a maximum RH of 60%. For details, see: http://www.chiltrix.com/documents/HP-ASHRAE.pdf

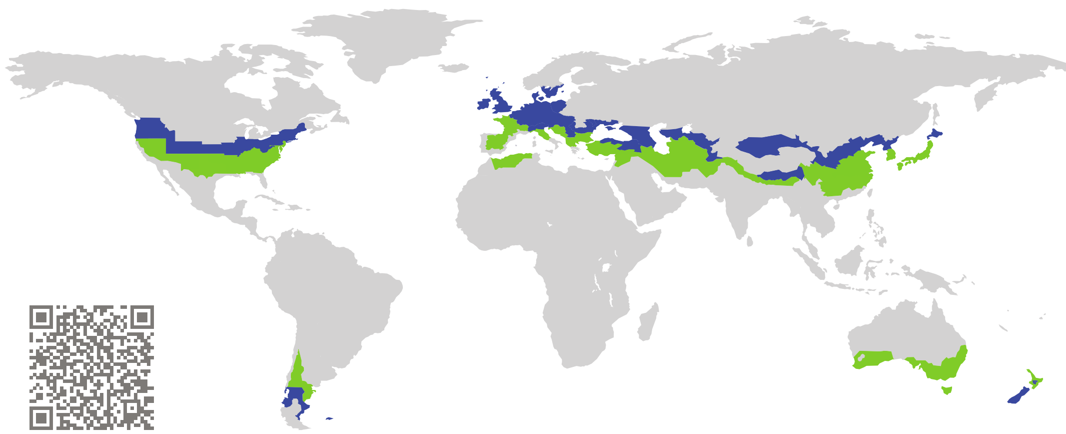
Residential:
For residential comfort, health, and protection against microbial growth, ASHRAE Standard 62.1-2013 recommends indoor RH up to but not exceeding 65%.

CERTIFICATE

Certified Passive House Component

Component-ID 0327vs03 valid until 31st December 2017

Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
Germany



Category:	**Air handling unit with heat recovery**
Manufacturer:	**Zehnder Group Nederland B.V.** **Netherlands**
Product name:	**ComfoAir200, ComfoD250, WHR920**

Specification:	Airflow rate < 600 m^3/h
Heat exchanger:	Recuperative

This certificate was awarded based on the product meeting the following main criteria

Heat recovery rate	η_{HR}	$\geq$	75 %
Specific electric power	$P_{el,spec}$	$\leq$	0.45 Wh/m^3
Leakage		$<$	3 %

Comfort: Supply air temperature $\geq$ 16.5 °C at outdoor air temperature –10 °C

Airflow range
60–150 m^3/h
Heat recovery rate
η_{HR} = 92 %
Specific electric power
$P_{el,spec}$ = 0.42 Wh/m^3

cool, temperate climate

CERTIFIED COMPONENT

Passive House Institute

www.passivehouse.com

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http://www.comfosystems.de |

Passive House comfort criterion

A minimum supply air temperature of 16.5 °C is main tained at an outdoor air temperature of -10 °C.

Efficiency criterion (heat recovery rate)

The effective heat recovery rate is measured at a test facility using balanced mass flows of the outdoor and exhaust air. The boundary conditions for the measurement are documented in the testing procedure.

$$\eta_{\mathrm{HR}} = \frac{(\theta_{ETA} - \theta_{EHA}) + \dfrac{P_{el}}{\dot{m} \cdot c_p}}{(\theta_{ETA} - \theta_{ODA})}$$

With

η_{HR}	Heat recovery rate in %
θ_{ETA}	Extract air temperature in °C
θ_{EHA}	Exhaust air temperature in °C
θ_{ODA}	Outdoor air temperature in °C
P_{el}	Electric power in W
$\dot{m}$	Mass flow in kg/h
c_p	Specific heat capacity in W h/(kg K)

Heat recovery rate
$\eta_{\mathrm{HR}} = 92\,\%$

Efficiency criterion (electric power)

The overall electrical power consumption of the device is measured at the test facility at an external pressure of 100 Pa (50 Pa, respectively, for the intake and outlet). This includes the general electrical power consumption for operation and control but not for frost protection.

Specific electric power
$P_{\mathrm{el,spec}} = 0.42\,\mathrm{Wh/m^3}$

Efficiency ratio

The efficiency ratio provides information about the overall energy performance of the respective ventilation unit. It specifies the achieved reduction in ventilation heat losses by using a ventilation unit with heat recovery rather than without.

Efficiency ratio
$\epsilon_{\mathrm{L}} = 0.67$

Leakage

The leakage airflow must not exceed 3 % of the average airflow of the unit's operating range.

Internal leakage	External leakage
2.84 %	0.80 %

Settings and airflow balance

It must be possible to adjust the balance of airflows at the unit itself (either between the exhaust and the outdoor airflows or between the supply and the extract airflows, if the unit is respectively placed inside or outside of the insulated thermal envelope of the building).

- This unit is certified for airflow rates of 60–150 m^3/h.
- Balancing the airflow rates of the unit is possible.
- The user should have at least all the following setting options:
  - ✓ Switching the system on and off.
  - ✓ Synchronized adjustment of the supply and extract airflows to basic ventilation (70–80 %), standard ventilation (100 %) and increased ventilation (130 %) with a clear indication of the current setting.
- The device has a standby power consumption of 6.10 W and therefore not complies with the target value of 1 W. The device should be equipped with an additional external switch so that it can be disconnected from the mains, if required.
- After a power failure, the device will automatically resume operation.

Acoustical testing

The required limit for the sound power level of the device is 35 dB(A) in order to limit the sound pressure level in the installation room. The sound level target value of less than 25 dB(A) in living spaces and less than 30 dB(A)in functional spaces must be ensured by installing commercial silencers. The following sound power levels are met at an airflow rate of 150 m^3/h:

Device	Duct			
	Outdoor	Supply air	Extract air	Exhaust air
49.0 dB(A)	64.7 dB(A)	57.2 dB(A)	54.1 dB(A)	67.1 dB(A)

- The unit does not fulfil the requirements for the sound power level. The unit must therefore be installed acoustically separated from living areas.
- One example of suitable silencers for supply and extract air ducts is mentioned in the detailed test report or can be obtained from the manufacturer. It is recommended to identify suitable silencers for each individual project.

Indoor air quality

This unit is equipped with following filter qualities by default:

Outdoor air filter	Extract air filter
G4	G4

On the outdoor air/ supply air side the filter quality class F7 is recommended. If not standard configuration, the F7 filter is available as accessory part.

Frost protection

Appropriate measures should be taken to prevent the heat exchanger and optional downstream hydraulic heater coil from getting damaged by frost during extreme winter temperatures (–15 °C). It must be ensured that the unit's ventilation performance is not affected during frost protection cycles.

- Frost protection of the heat exchanger:
  - ✓ In order to guarantee safe operations of the device also at low outdoor air temperatures without reducing the supply air flow rate, the manufacturerrecommends either an internal or external preheating coil. Therefore the manufacturer provides the optional electric preheating coil HRI 40 20 with a heating power of 900 W. In case of a subsequent installation the frost protection component is also available as an installation kit.
- Frost protection of downstream hydraulic heater coils:
  - ✓ In order to protect a downstream hydraulic heater coil the device is switched off as soon as the supply air temperature falls below 5 °C. In this case the display will show an error.