Energy Infrastructure R&D Test Laboratory

BUILDING REQUIREMENTS

Laboratory R&D Goals

Direct-to-Surface Solar PV Goal: Develop low cost plug-and-play standard for mounting solar PV direct to plywood roof and wall, without shingles and without side clapboards, at a cost lower than traditional non-solar surfaces. More…

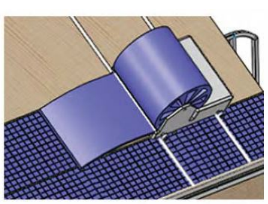
Next Generation Solar Farm Goal: Reduce cost of solar on land via plug-and-play PV standardization and automation. More…

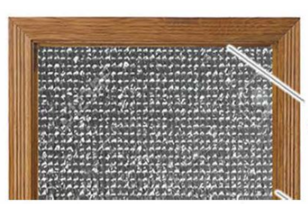
Solar Thermal Energy Storage Goal: Develop standard for storing thermal energy in a tank of H_20 or block of cement, to provide heat or cold when the sun goes down.

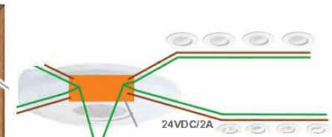
Next Generation IOT and LED Lighting Goal: Develop standard for attaching windows, doors, lights, ceilings and walls to network: 99.999% reliable, < $1 per node electronics, supports tree wiring, processor sleep when not in use. More…

Window Thermal Cover Goal: Develop low cost standard for covering windows with flat (e.g. 2" R12 XPS) or rolled motorized insulators. More…

Automated Drilling Goal: Reduce cost of drilling into soil via automation & advanced techniques. Water circulating between 55°F soil & building reduces HVAC energy significantly. More…







Chapter 1) Introduction

This document describes an Energy Infrastructure R&D Test Center that is used by university researchers to develop low carbon technologies. For example, researchers can use this to practice attaching solar material direct to plywood. This structure takes the form of a 2000 square foot house that is fully automated and uses zero net energy without burning natural gas in a cold climate, over a year, where the grid is used for electrical storage. This is placed near a university campus and is used by researchers to test hardware and software inventions that reduce fossil fuel use. This structure has a ratio of 1:1 between indoor sq ft and solar collector sq ft, which is massive by today's standards (e.g. 2K sq ft house with 2K sq ft solar). This "house" is designed to support comfort demanded by Americans in a cold climate (e.g. many warm rooms in Boston during January without burning natural gas). Researchers live in the structure, in addition to utilizing it as a test site. They pay the utility bill, or receive money if net positive.

Each year Seymour Cray, founder of Cray Computers, built a sailboat, raced it, and then burn it on the beach at a big party. The demolition helped researchers focus on next year's project, which was another sailboat. ZE1 is Manhattan 2's first house. Yet researchers will think of ways to improve, and want to build more ZE structures. The next will be called "ZE2", and so forth and so on. Unlike Seymour, we will not burn our houses at a big party. Instead, they will be occupied by researchers who will become more familiar with ZE living.

The basic 2k sf house is completed within 12mths. Upon completion, solar is installed and temperature is maintained using a traditional HVAC controller, yet very little automation is implemented. ZE1 is made available to researchers, free of charge, to design and test various hardware and software that reduce fossil fuel use, and implement automation. The results of their research is made available to the public, free of charge, per the Manhattan 2 Engineer Agreement.

Chapter 2) Exciting Areas of Research

ZE1 is a test facility that supports important areas of research.

Solar Packaging and Installation Cost Reduction Research

The cost to install solar, parts and labor, is typically $3 per watt. 2K sq ft is approximately 30KW ($90K). The cost of the top 1mm solar conversion photovoltaic cell is $0.17/Watt. Therefore, 6% of the cost is for solar PV cells and the rest is installation labor, support mechanical structure, and electronics. Researchers need to reduce this cost, dramatically. ZE1 provides roof plywood at a 35degree angle with which researchers can attach prototype panels for testing (e.g. 1x2meters, direct to plywood). Also, researchers can attach solar prototypes directly to walls. For more details on solar packaging research, see http://www.ma2.life/doc/plan/MASPII.pptx.

Solar Cell Switching Research

Currently solar panels produce a fixed 48VDC that is fed into an inverter which produces 110VAC. This is inefficient, is expensive, and is prone to break. Researchers work on routing different DC voltages from solar cells to a central switch bank which then delivers computer programmable AC and DC voltages to the various consumers of electricity in the building (e.g. 32VAC at 15Hz instead of 110VAC at 60Hz). A motor, for example, might prefer to run at 10% speed continuously rather than 100% speed for 6 minutes every hour.

Refrigerator, Clothes Washer/Dryer, Disk Washer, Oven -- Energy Integration Research

Large appliances that use energy are pressed against ZE's utility room wall and a port in the wall provides access to the inside of the appliance. These are then rebuilt by researchers to use the central HVAC compressor, ground source (55°F water), variable voltages and frequencies from solar, and stored hot/cold water from solar. An example application is to route ground source 55°F water to refrigerator ground source heat pump, instead of air source heat pump, and reduce refrigerator energy consumption 2x to 3x.

Last 10 meters Research

The networking term "the last mile" refers to routing internet data to homes and businesses. Now we need to route power and data to the last 10 meters -- to doors, windows, occupancy detectors, fans and dampers in ducts. Researchers use ZE1 as a test site to place their prototype hardware and software. For more details, see http://www.ma2.life/doc/plan/L10m_MIT.pptx.

Ground Source Installation Cost Reduction Research

A ground source (55°F underground water flowing through HVAC system) dramatically reduces energy consumption, yet it is expensive to drill into the ground. Researcher study ways of reducing this drilling cost, and use this site to test their prototypes (i.e. they drill holes in backyard). For more details, see https://www.manhattan2.org/automate-installation-of-gshp

Chapter 3) ZE Laboratory

Different areas of ZE1 are allocated to different groups of researchers.

Solar Storage Laboratory

The 800sf basement is dedicated to research on zero energy HVAC and energy storage. We start with a ground source heat pump and 500gallons of water for heat/cold storage. The 30KW solar heats 500 gallons of water to 150°F during 4hrs of sunlight, and then over 20 hours, this water is used to heat the house during the winter. A $5K tank of water can store 100kWhr, which is ten times less money per kWhr than a battery (e.g. Tesla 13kWhr $6k battery). Researchers rebuild, rework, and improve the initial HVAC/Storage system; and also add parallel HVAC systems where only one is operational at a time.

Architectural Form Laboratory

The front of the house is dedicated to research in making ZE visually appealing. Architects study how to make ZE accepted by a neighborhood, home owner, and city planner. ZE architects study placing solar on the front of the house that connects nicely with form (e.g. solar awning above walkway) and look at adding visually appealing accents (e.g. accent lighting on the solar panels themselves). ZE architects can rework the front to test different concepts. An example is Architects Jane adds solar awning above walkway using timber framing. It is deployed for several months and then replaced with a different type of solar awning by Architect Jill that uses aluminum framing. Each is extensively studies by civil engineers and mechanical engineers who look at things like durability, UV resistance, and ability to resist large winds. The results of all analysis are placed at the manhattan2.org website enabling architects worldwide to see comprehensive analysis of various techniques.

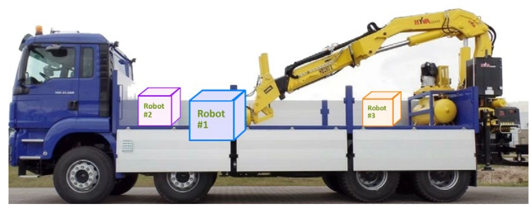
Windows Laboratory

The sides and back of the house are dedicated to research on windows and window treatments. Researchers install and test prototype windows and devices. This includes motorized rolled thermal blankets and ~2" inch thick blocks of rigid insulation that deploy from inside the wall and cover the entire window (e.g. slides down from above). Much heat is lost from windows, yet seldom are they used by people -- most of the time they should be turned off.

Vacuum Insulation Laboratory

0.75" cavities are placed under drywall (e.g. 7ft x 14.5" x 0.75") for researchers to install vacuum insulation panels that are maintained by vacuum pumps and small microprocessors. Researchers also look at pumping air in-between window panes, in rolled window thermal blankets, in rigid slide down window covers, and around high energy appliances.

Solar Robotics Laboratory



A portion of the backyard is dedicated to research on robotic machines that build solar on metal framing, install solar on roof, and install solar on walls. Researchers are given a truck with a mechanical arm and robot bolted to the truck to test their software and devices that attach to the mechanical arm. This truck is placed in ZE1's backyard along with a pile of aluminum framing materials. Researchers develop different attachments for the mechanical arm, each of which perform a different function.

Urban Automated Drilling Laboratory

A portion of the backyard is dedicated to research on developing automated machines that drill holes in the ground to install a ground source for a heat pump (i.e. circulate 55°F water to reduce heating and a/c energy consumption 2x to 3x). We refer to this as the "Urban" drilling lab because we assume we are drilling in an urban area and therefore will not create a pond for drilling fluids (ponds increase resistance from neighbors and city). Instead, drilling fluid is circulated through a tank on a truck. To save drilling cost and reduce drilling fluid volume, the drill diameter is small (e.g. 3" instead of 9" w/ typical vertical bore hole). Also, to help reduce cost, we look at inserting HDPE 55°F water circulation pipe at same time as drilling and abandon drill head. Researchers are free to install pipe into the backyard (e.g. 50 to 200ft deep), attach to heat pump, and measure thermal heat capacity of ground source. After several years, this site might contain many ground sources, where only one is used at a time.

Small Happy Living Laboratory

We define "Small Happy Living" (SHL) as living in a small space where occupants report being happy (w/o Prozac). Researchers work on this at the SHL Laboratory, which is 300sq of bedroom space for 4 people. Small living reduces energy significantly. For example, 75sf per person consumes half as much HVAC energy as 150sf per person.

What does it take to make a person happy while living small? Reduce sound between rooms? Closed personal space for one person? Optimal control over temperature? Control over airflow between rooms? Social scientists interview test subjects to get a sense as to what is important. An example question might be, "What would you rather have, 200sq w/ sound from neighbor or 75sq that is absolutely quiet?" Also, researchers explore costs and create various models.

SHL inherently saves money due to smaller space (less labor and material for walls), and subsequently can redirect savings to amenities such as more temperature control, more sound insulation, more control over outside ventilation, no material outgassing, and good storage (e.g. 100cubic feet of drawer/shelf storage per person). A family of four in Hong Kong typically lives in 500sf; therefore, smaller living is possible. Yet how can you make it desirable to the extent that the American does not run away? That is the question for researchers at the Small Happy Living Laboratory.

Under the Triangle (UTT) Design Laboratory

Big solar at a 35° angle creates much space with reduced headroom "under the triangle" (UTT). UTT researchers study ways of making use of this space. One technique is to redirect storage from traditional closets and furniture (e.g. book case, dresser drawers), and toward UTT cabinets and drawers. ZE1 implements multiple techniques for UTT storage, one of which is a 8' x 4' x 1' "horizontal book case" which rests flat on the floor, on wheels or rails, and slides 8' into the UTT. This is used for heavy items such as books and papers. Two of these side by side would hold 64 cubic feet, which is similar to three 3x6x1' book cases or five filing cabinets with 4 drawers in each filing cabinet (64 / (3*4)). One could then place *more* drawers and shelves above this 8x4x1 heavy roll out.

The 1.5x1x1' totes in the photograph to the right are $8 each. A 4'x8' sheet of 0.75" thick plywood that slides into UTT could hold 20 of these totes (32/1.5) with a total tote cost of $160 (8*$20). From the front, this "drawer" would only consume 2'x4' of wall space, yet provide massive storage. And total cost would be reasonable.

ZE1 shelving/drawers in UTT are held in place with screws, enabling researchers to easily replace and modify. Massive UTT storage can help create a clutter free environment in ZE structures, to help encourage acceptance and make use of Under the Triangle. Just say "no" to clutter.

Solar Power Management Laboratory

Initially, DC electricity from solar arrays is routed to an inverter in the basement which creates 110 and 220VAC voltages (i.e. traditional method of handling solar power). Later, researchers route different DC voltages from solar (e.g. 48V, 24V, 12V, 6V, 3V and 1.5VDC) to a switch bank in the basement that combines them to create variable AC and DC voltages at different frequencies, which are then routed to appliances and motors throughout the structure. Details of how this works will be determined later.

One Meter Grid Laboratory (OMGL)

In the future, structures might be assembled on a one meter grid. For example, windows are spaced every N meters, where N is an integer, vertical 2x6 framing in walls are spaced every 0.5 meters, etc. This might transpire due to the need to mechanically synchronize pre-fabricated walls, doors, windows, covers for windows (e.g. rigid 2" XPS block that slides down) and solar fabric (with internal conductors and electronics spaced on a 1 meter grid). The One Meter Grid Lab explores this and looks at how the various components might fit together (i.e. doors, walls, window covers, solar PV sheathing). Moving to a 1 meter grid would also have its costs, and this is explored as well.

OMGL looks at how one might migrate from existing systems. For example, European plywood is typically 2.5m x 1.25m (8.1ft x 4.2ft) whereas USA plywood is 8x4ft. How could both migrate w/ least pain?

OMGL looks at market forces that might move this forward. For example, 1 meter wide rigid window covers (e.g. 2" thick, R13, slide down from inside wall) for 1 meter wide windows would save tremendous energy, since most energy is lost through windows. And a 1 meter grid would help mechanically synchronize windows, window cover mechanisms, internal wall framing, and solar PV sheathing on outside wall (w/ internal electronics that is cut to fit around window).

If one starts with a variable called "U" (sort of like "X" yet U standards for "standard unit") and "P" is width of framing (e.g. 1.5" with 2x6) then one could theoretically look at spacing windows at N*U (N is integer), making window width U-P, horizontally spacing vertical framing at U/2 (instead of 16"), having space between framing of

U/2-P, setting width of rolled PV solar sheathing to U, spacing electrical circuits within rolled PV solar sheathing to U (to allow one to cut PV solar material for windows w/o doing too much damage to internal electronics). The Americans might favor setting U to 32" to match existing 16" frame spacing, whereas metric people might favor 1 meter. OMGL (aka "oh my god lab") explorers ways to reduce pain to both parties.

Chapter 4) Large Utility Room touches (almost) all Rooms

A large utility area in the center of the structure touches (almost) all rooms. All water faucets and toilets are mounted or pressed against utility room wall, to allow easy access to researchers that might want to modify or add. Large energy appliances (e.g. refrigerator, clothes dryer, oven, and dishwasher) are pressed against utility room wall. Also, for each, we have two. One is the primary commercial unchanged unit that supports occupants, and the other is the prototype rebuilt unit. Initially, prototype space is kept empty. Researchers rebuild appliances to better integrate with solar, 500 gallons of heat/cold in basement, and ground source heat pump. HVAC researchers use the utility room to route pipes, ducts, and wire. The 1st floor 100sf utility room is directly above the 2nd floor 100sf utility room, which is above the 800sf basement. If we have a 3rd floor, then it would be possible to not have a utility room on this floor and instead access 3rd floor rooms from 2nd floor utility room ceiling.

Chapter 5) ZE1 Building Design Requirements

Below is a list of ZE1 design requirements.

Overview

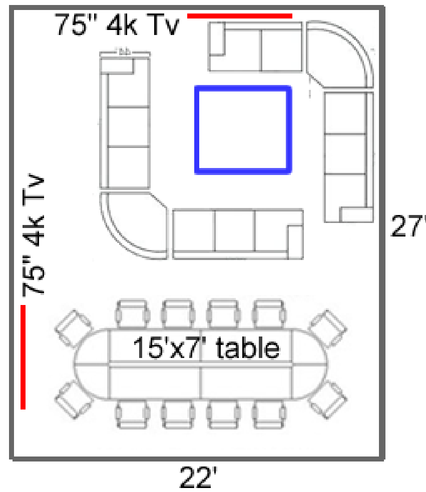
- 2000 square feet of indoor usable floor space
- 2000 square feet of solar collectors at a 35° physical angle to horizontal (0° is flat roof), which is optimal for Boston (~30KW).
- ~8% ratio (160sf) of window to floor space (which is less than typical 18%). This is a small number, yet we need this to reduce heat loss through windows, which is massive in a typical house. If we had 2" thick motorized rigid window covers, then we could increase this number significantly, yet initial construction will not include those covers. Perhaps ZE2 (next house) will have big windows w/ R13 rigid covers that slide down from inside wall?
- The house is either 2 or 3 floors (above basement), as noted in following chapters and drawings.
- All rooms are individually temperature controlled (7 zones).
- Occupancy detectors determine which rooms to support.
- A tank of water stores heat/cold to be used when the sun goes down.
- Solar power drives ground source heat pump that produces hot or cold water and support house heating/cooling.

Rooms

- The master bedroom (BR1) is ~270sf and a second comfortable bedroom (BR2) is ~220sf.
- Bathroom1 is ~70sf (e.g. 8'x9') and supports BR1, BR2 (floor 2?)
- Bathroom2 is ~50sf (e.g. 6'x9') and supports BR3, BR4, BR5 (floor 3?)
- Bathroom3 is ~30sf (e.g. 6'x5') and supports living room / dining room / kitchen (floor 1?)
- Stairs consume ~50sf per floor (e.g. ~150 for ~3 floors and this is part of the 2000 sf)
- 300sf is dedicated to placing people into small spaces, and making them happy. This 300sf area contains 3 bedrooms (BR3, BR4, and BR5). Alternatively, these rooms could be used as an office or a guest room.

- A ~320sf kitchen is fully enclosed, which enables this room to be temperature controlled at breakfast time w/o involving the rest of the house. It supports seating 4 people either at a counter or table.
- This leaves ~600sf for Living Room and Dining Room (2000 - ((70+50+30) + (270+220) + (320) + (300) + (150))). This room supports typical living room/dining room activates, and also is used as a meeting place for ZE researchers.

Living Room / Dining Room



- The living room / dining room contains a 12' to 15' long conference/dining table that seats 12 to 14 people. A 75" 4k TV ($1K) at one end supports a computer input.
- Couches are placed in the living room area, with another TV. Subsequently, several researchers can watch one TV while others discuss their latest design on the other. Two TV's help reduce terrible fights over whether to watch to game or discuss thermal analysis.
- The top surface of the conference table is Formica (plastic, not wood, typical for work surfaces) which resists water and does not require placemats.

Small Happy Living Lab (BR3, BR4, BR5, Bathroom2) -- 300sf

- Supports 4 occupants in three bedrooms that consume 300 SF total (2 people in BR3, 1 person in BR4, 1 person in BR5)
- 100 cubic feet of storage per occupant (400 cu ft total), most of which is UTT and not counted in 300sf (all UTT is not counted in 2000 sq ft indoor usable floor space).
- BR3: ~150sf, 2 beds built-in, ~200cu ft storage in triangle area under solar (not counted in 150sf)
- BR4: ~80sf, 1bed, ~100cu ft storage (counted in 80sf or UTT)
- BR5: ~70sf, 1bed, ~100cu ft storage UTT (not counted in 70sf)
- Bathroom2 is near these three BR's.
- Advanced sound insulation for each BR; including floor, ceiling, walls and door
- Independent temperature control over each BR
- Independent ventilation (outside air) control over each BR
- HVAC does not mix air between BR's (e.g. radiator and air circulation within room does not open to duct bus A or B); subsequently if one BR uses hair spray, the other BR does not smell it.

BR3 (150sf)

- built-in bunk beds, twin on top, queen on bottom, built-in stairs provides access to upper bunk
- built-in desk
- nicely stylized (visually very appealing)
- Supports 2 children, or 2 guests, or could be used as an office
- 200 cu ft of UTT storage (not counted in 150sf)

BR4 (80sf)

- Supports 1 person, no built-in items (occupants fills w/ furniture as needed)
- Does not have access to UTT, therefore 100 cubic feet of storage are provided w/o UTT

BR5 (70sf)

- Supports 1 person, no built-in items (occupants fills w/ furniture as needed)
- Possibly push bed UTT?

Has access to UTT for 100 cubic feet of storage

HVAC

- Heat pump supports heating and cooling with electricity. We might need ~8 tons to support ~130A/220V heating of water for 6 hours each day.
- Ground source attaches to Heat pump.
- Water storage is used to store heat and cold. We might need 500? gallons, which is 8ft x 5ft horizontal tank that weighs 5000 LBs when loaded w/ water; and 1500 LBs when empty.
- Individual temperature control over each room (e.g. 7 zones)
- Can move air to/from any two rooms (via ducts bus A and bus B). For example, one is watching game on TV at 9:30pm and system moves air from living room to bedroom (mixes) and adds some energy 30min before you go to bed at 10pm.
- Each room has individual control over receiving outside air (via ventilation bus duct C)
- Ventilation system connects to heat exchanger (cold air comes in and is warmed by outgoing air) and multiple vents are used to pull air from one side of house or the other (i.e. select high pressure side).

Basement

- Basement is 800sf and is not counted in the 2000 sf indoor livable sf.
- 9ft headroom from floor to ceiling insulation (supports larger machines).
- Double-doors at basement egress to support installing large machines (e.g. 1500LBs 8x5ft water tank), large heat pump, etc. Do we need slopped surface to door, to support wheeled equipment?
- Cement floor, center block walls
- >= R10 insulation is attached to basement walls (e.g. 2" PIR rigid foam board).
- Insulation under cement floor -- to be determined (TBD)
- Basement ceiling is covered with R50 insulation (e.g. 2" PIR R13 + R38 batt).

Floors

- Internal floors are covered in oak wood (??), unless otherwise noted.

Utility Room

- ~100 sf is allocated for utility room on 1st floor, and ~100 sf (e.g. 7x14') for utility room on 2nd floor; with these directly above each other. This is not counted in 2000 sq ft. Almost all rooms touch a utility room to help researchers gain access to room, and to help move energy to and from rooms w/ little loss.
- Utility area supports HVAC, ducts, electrical wires, control wires, interfacing/integration of energy appliances.

Insulation

- Thermal insulation is placed in internal walls and floor, to support different temperatures in each room.
- R40 insulation in exterior walls (e.g. 2x6 foam R23 + 2" PIR R13 + 2" XPS R10)

- R50 insulation under first floor (e.g. 2" PIR R13 + R38 batt).
- R80 insulation under roof
- R38 Batt Insulation is placed under 2nd floor and under 3rd floor to thermally isolate floors.

Windows

- Windows are to have >= R4 thermal conductivity (e.g. triple pane). We are not to rely on manufacturer claims and instead focus on 3rd party data. Adding a glaze to a piece of glass does not increase its R1 thermal conductivity from 1 to a big number. Argon is lost over time and is therefore less interesting.
- We add cavities above (and possibly below) all windows (inside of wall) that support 2" thick motorized rigid insulation that slides down (and/or up) and covers entire window. Also, internal cavity supports rolled insulation (e.g. 5" diameter roll).
- Conduit connects each cavity to utility room, enabling researchers to add wire as needed.
- Windows & molding around windows are held in place with screws (no nails, no glue); therefore researchers can easily remove, replace, and modify.

Internal Doors

- Internal doors are thermally insulated, to help individually control temperature in each room.
- Weather stripping is placed around the perimeter of each internal door, to stop air flow. Normally one uses gap at bottom of internal door for central air return flow, yet we have duct bus A and B for this purpose. ZE1 Internal doors are a little like external doors, in that they are thermally insulated and stop airflow.
- We monitor the position of all doors and a motor in each allows computer to either open or close.
  This helps us control temperature in each room, move air from one room to another, and use outside air (e.g. cold night air cools internal warm room).
- Cavities above each door are created to house prototype devices that assist in the above tasks.
- Conduit connects these cavities to utility room, enabling researchers to add wire as needed.
- Conduit inside door itself connects area above door to latch. This enables researchers to place devices at latch area to unlatch door.
- Doors & molding around doors are held in place with screws (no nails, no glue); therefore researchers can easily remove, replace, and modify.

Active Wall Cavities

- 0.75" thick cavities are placed under drywall to provide researchers with a place for active insulation (e.g. 0.75" x 14.5" x 7ft). These are spaced at 16" intervals (i.e. corresponding to 2x6) and one can access them after removing both upper and lower horizontal molding with screws or bolts.
- ~1/8" thick hardboard (?) is mounted on inside surface of wall 2x6, low thermal conductivity 0.75" furring strips (e.g. 1.5" x 0.75" x 7ft, honeycomb polycarbonate?) are placed on hardboard at 2x6 position, and then drywall is mounted on furring strips. Currently this kind of thing is labor intensive, yet ultimately active walls (electronics + vacuum) with very high insulation and low cost might be pre-fabricated and made to order (i.e. where computers make sure product matches house drawings).

Under the Triangle

- Much storage is placed under the Triangle (UTT). This is not counted in the 2000 sq ft.
- Shelves, Cabinets and Drawers UTT are held in place with screws (no nails, no glue) allowing researchers to easily replace and modify.
- Details are TBD (to be determined).

Molding

- Molding around doors, windows, at floor base, and ceiling is held in place with screws to provide easy access (e.g. small torque head, no nails/glue). This enables researchers to easily access last 10meter wiring, active insulation (vacuum), windows, and doors.
- Molding is placed at floor base, and also at floor/ceiling interface (e.g. crown molding). Researchers gain access to active insulation cavities after removing molding.

Energy Appliances

- ZE1 supports two refrigerators, two ovens, two dishwashers, and two clothes washer/driers; and places all against utility room wall. Initially, we install only one of each type. Later, researchers can add prototype units. This facilitates the design and testing of (rebuilt) appliances which better integrate into ground source (55°F water), central HVAC heat pump, stored hot/cold water, and solar panels.

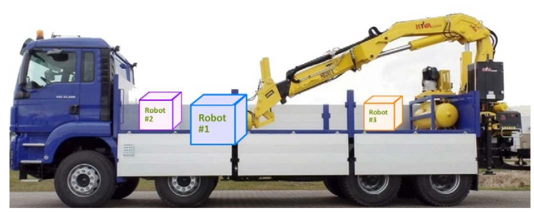
Aesthetics

- The front looks nice and fits into the neighborhood. It is assumed the sun approaches from the back, and the back visually is dominated by 2k sf of solar (the back faces south). The front is dedicated to researchers who create a beautiful ZE look (e.g. solar awning over walkway, accent lighting on solar).
- We lose control over aesthetics at the sides and back due to researcher's prototypes that create a visual mess.

Garage/Carport

- Two cars fit under a carport or in a garage.

Backyard Solar Robotics Laboratory



- The back yard is dedicated to designing and prototyping robotic devices that handle solar. This includes a truck with a robotic arm that practices assembling and disassembling solar over metal framing, and assembling solar on walls/roof. Initially, we set up an open space and let the robotics people add as needed.
- Ground covering will be determined later (e.g. grass, gravel).

Solar Power Management Laboratory

- Electricity from solar arrays is routed to a central location in the basement.
- Initially, we use a traditionally inverter to create 110 and 220VAC voltages. Later, researchers switch different voltages from solar (e.g. 48V, 24V, 12V, 6V, 3V and 1.5VDC) as part of their research to use electricity more efficiently. An example is lighting. LED devices ultimately required 1VDC. In a typical solar system, 48VDC from solar is routed to an inverter, which then creates 110VAC, which is later converted to 1VDC at the light bulb, which gets hot (heat is wasted energy). A more efficient system would bypass the inverter. HVAC motors often would rather run at variable speeds, yet this is difficult when powered by 60Hz sinewaves. Integrating solar, HVAC, motors, and lighting more efficiently can save a tremendous amount of energy. 75% of energy generated in the world is wasted during transmission and conversion. Electrical engineers have much work to do and can use ZE1 as a testbed for their research.

Monitoring and Control

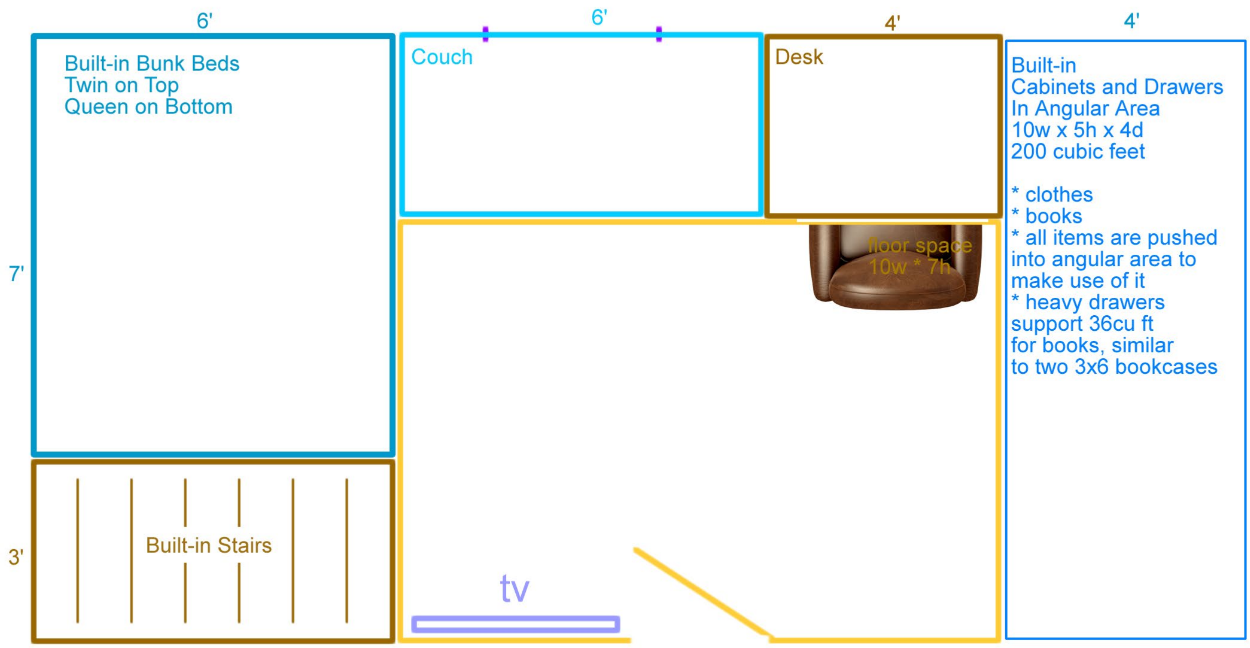
- Many temperatures and pressures are monitored throughout the system. An example method for monitoring over 50m distances would be to distribute LabJack T7 $429 Ethernet data acquisition systems throughout structure and connect them with an Ethernet router.
- Each room has both a lower and an upper HVAC vent. Researchers explore measuring temperature, pressure, and air flow at each vent. One option is to combine an Arduino processor, powered Ethernet shield (PoE), and a small custom PCB with accurate pressure sensor (e.g. MS5607-02BA03, $1.20) and an accurate temperature sensor (e.g. ±0.1°C, #SI7051-A20-IMR, $2). This might cost $100 per node. One could also connect more sensors to each node, as needed:
  https://www.dfrobot.com/category-85.html
- One could also place the above measurement device at water pipes, water storage tanks, and heat exchangers.
- The strategy for ZE1 is for it to be "over instrumented". This means you add more sensors than you think you need, and therefore can see unexpected issues more quickly. It is often faster and less money to add a bunch of sensors quickly, then to spend much time debugging (engineering time consumes massive amounts of money). 50 of these nodes and a PoE (powered) Ethernet router might cost a total of $8k, which is reasonable. This would support researchers working with HVAC, energy storage, ground source, heat pump, energy movement, happy living, window insulation, and active wall insulation (i.e. vacuum packs in walls).

Last 10 meters

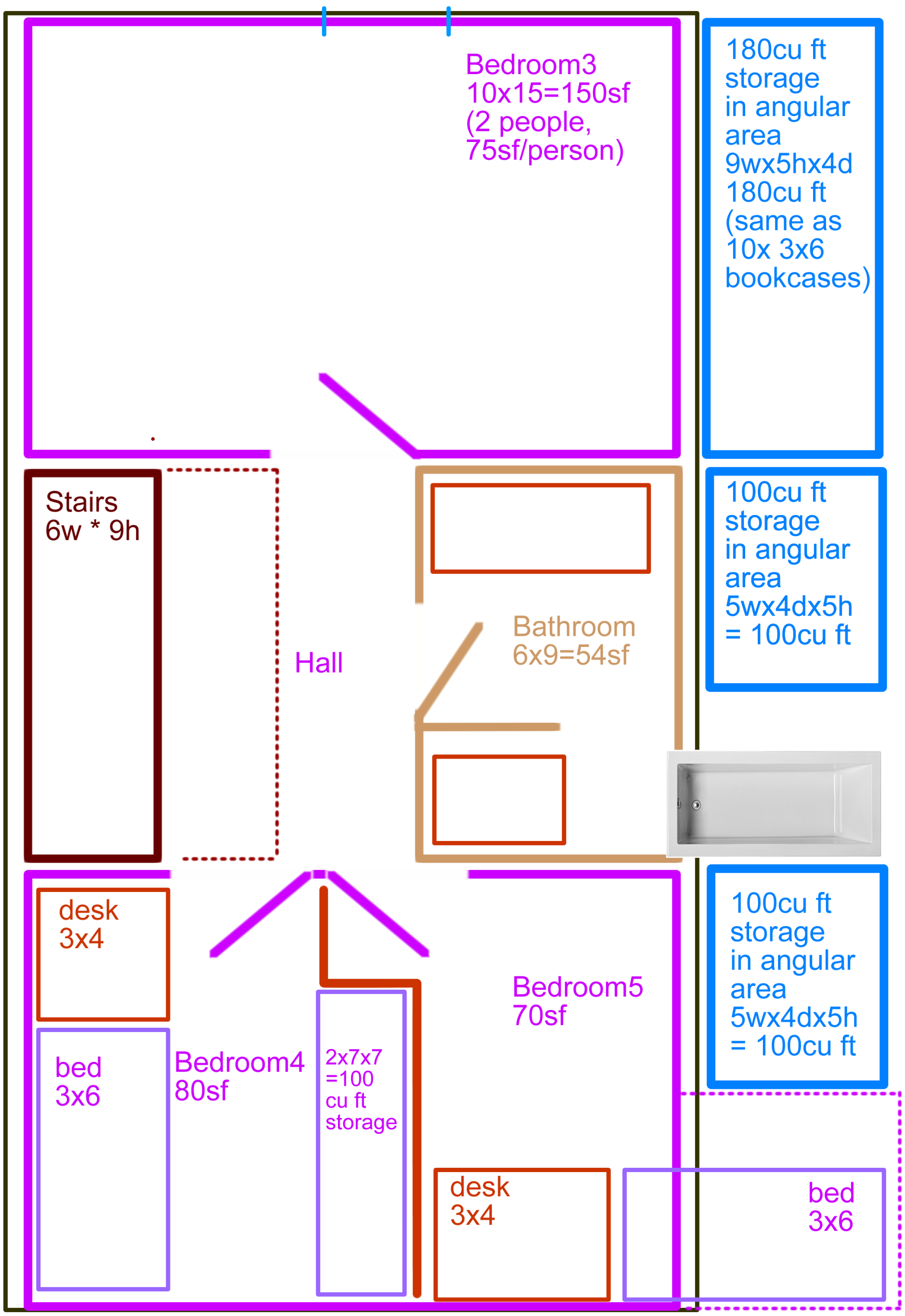
- Conduit (i.e. pipe) connects utility room to all electrical boxes enabling researchers to install wire to those locations.
- 4 wire cable is routed in parallel with all 110vac power wires, and is also routed to all cavities created above and inside windows and doors (i.e. for wallbus signaling). All 4 wire cables terminate at the "automation box", which is an electrical box next to the fuse box.
- Conduit connects research cavities above doors and above windows to utility room, enabling researchers to add wire as needed.
- Internet Fiber or Coax Cable enter structure, is routed to a modem and then to an Ethernet Wi-Fi router.
- All communication with onsite devices must be five 9's reliable (99.999% of the time it works). This means Wi-Fi and power line communication is not allowed for any device that physically mounts on the structure. Wi-Fi (two 9's if you are lucky) is only used for untethered devices (e.g. phone, tablet, and computer). The reason for this is that unreliable products will ultimately fail in the marketplace and be replaced with reliable products, and we want engineers to focus on things that are more likely to be successful.
- In ZE1, we are looking at $100 per node sensor monitoring via Arduino Powered Ethernet. Perhaps ZE2 (next house) will have $5/node wallbus monitoring with same accuracy?

Chapter 6) BR3 - Nicely Stylized 150sf BR for 2 people

Below is an example of built-in bunk beds plus steps in a nicely stylized room. This room is an exercise in making an appealing BR for 2 people in a relatively small space (e.g. 75sf/person), to the extent that it is desired by the typical American.

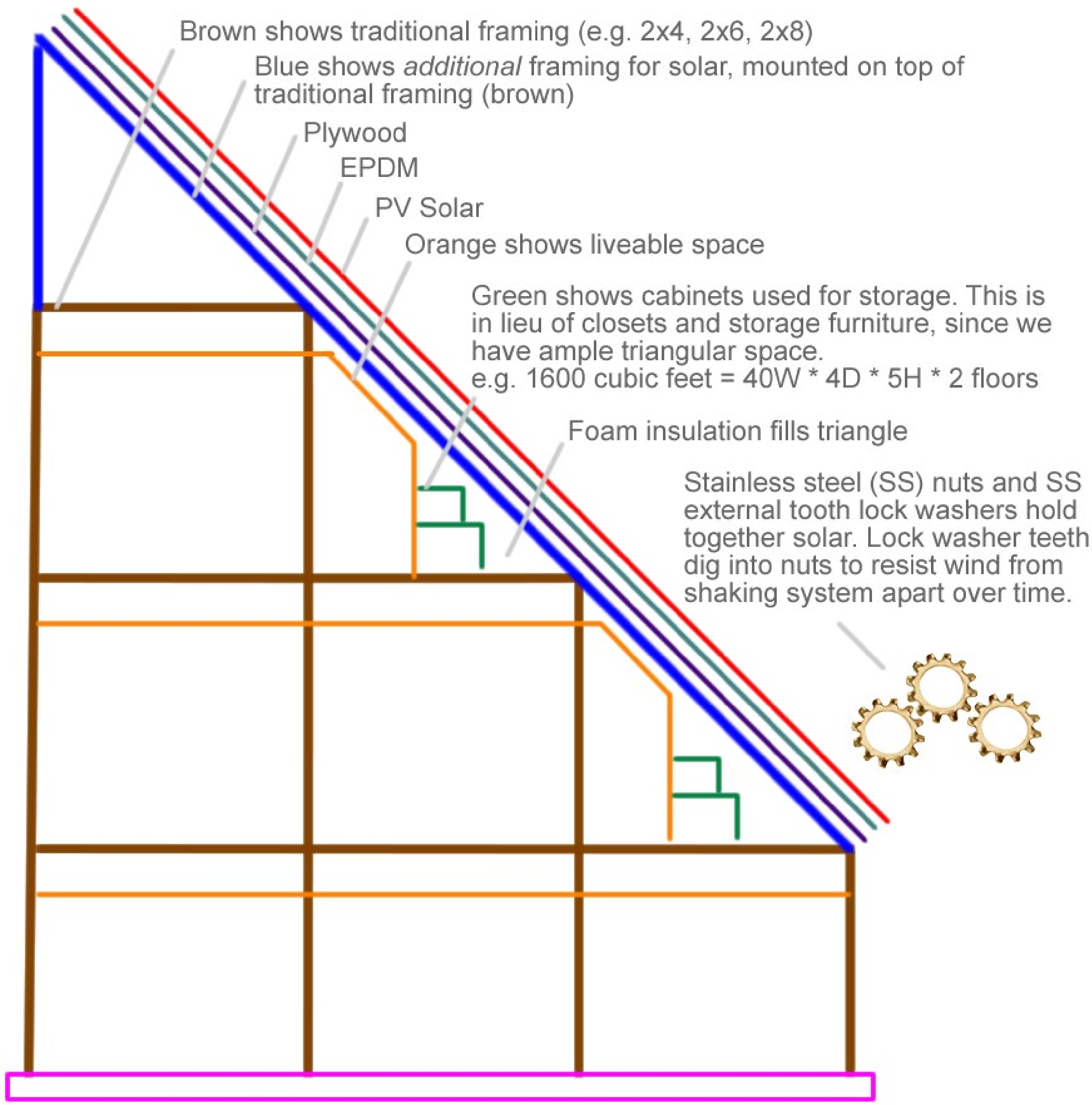


Below is an example of how one might arrange 3 BR's in a small space.



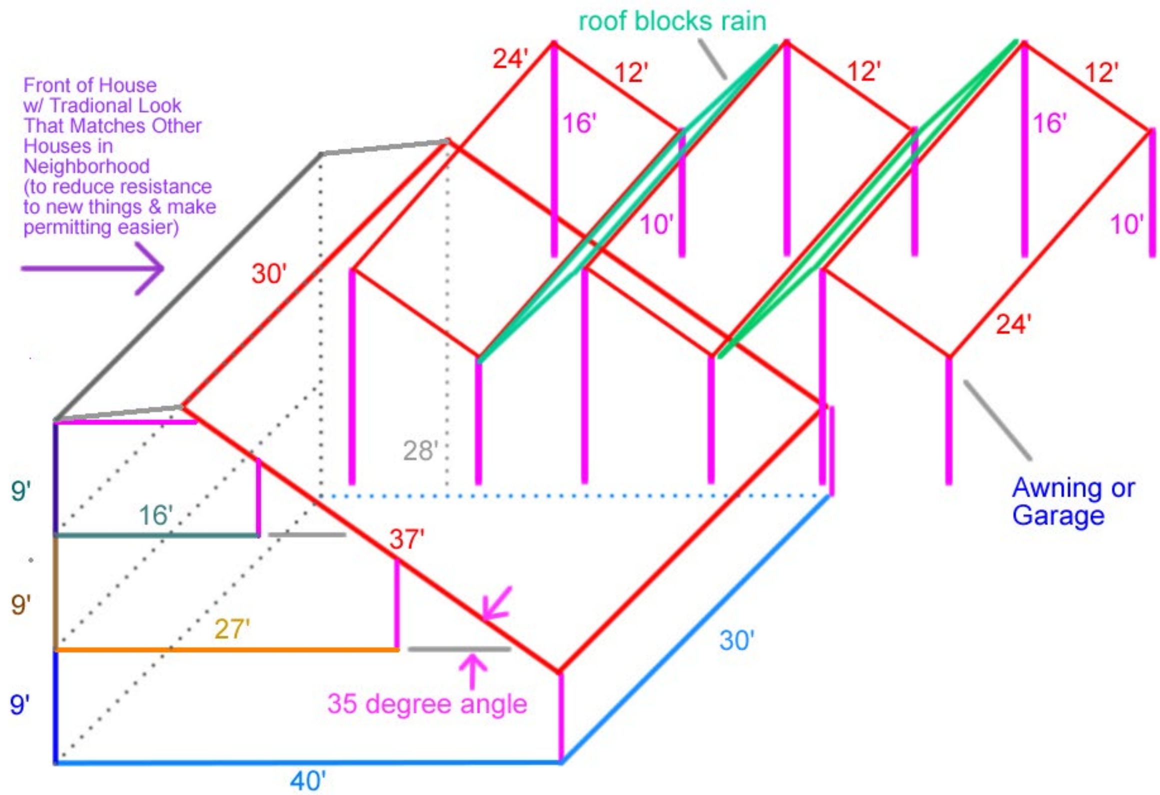
Chapter 8) Big Solar At Optimum Angle

The below illustrations shows what one might do with a 45° roof (e.g. ideal for Canada). Blue lines show solar support framing on top of traditional (brown) framing. Roof consists of 2x6 solar support framing, plywood, EPDM rubber, and PV solar. The ideal solar angle in Boston is 35° (less angle), yet has similar issues. This drawing shows a total height of 4 stories, which would not fit visually into the typical neighborhood (even if solar faced backyard) since most houses are 1 to 2 stories.



Chapter 9) 2K solar over 3 Story House and Carport/Patio

The below drawing illustrates 2k sq ft of 35° solar on a 3 story 2k sf indoor floor space house. The maximum solar above the house is ~1100sf (30ft max structure height). The 900sf balance is placed over garage/carport/patio. One could build a traditional garage with walls that match house walls and/or place a solar awning over patio w/ pavers.



(16+27+40) = 83ft, discount 20% for non-usable space, this is 83*.8=66 total floor width (3 floors combined).

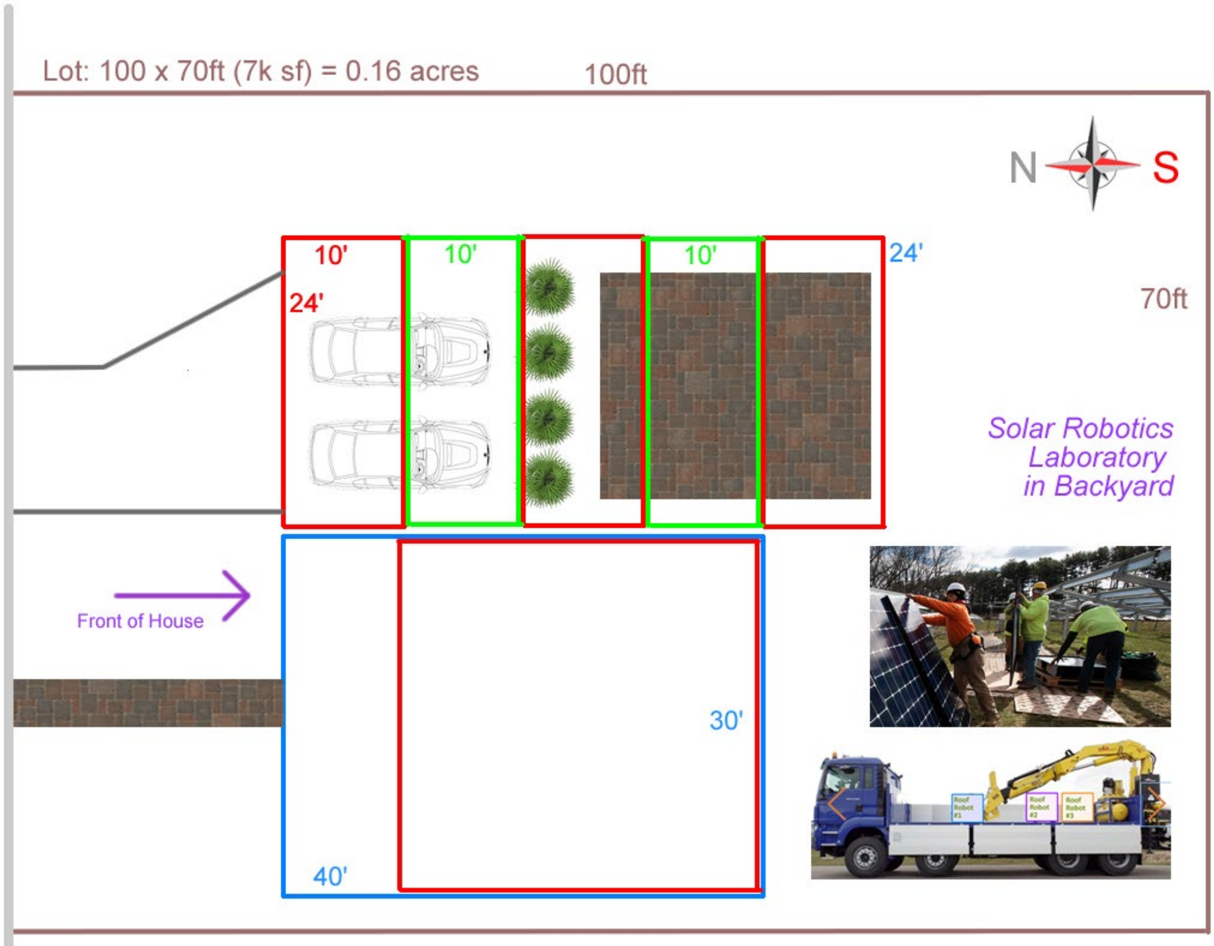
2000 indoor sqft / 66 width = 30ft length (depth in dwg)

37 * 30 = 1100 sq ft solar above main house

to get 900 more, we add 3 awnings above cars, 300sf each, 24ft wide (24w * 12L)

Chapter 10) 0.16 Acre Lot with 2k Solar

The below drawing shows how one might fit the previous house into a 0.16 acre lot.

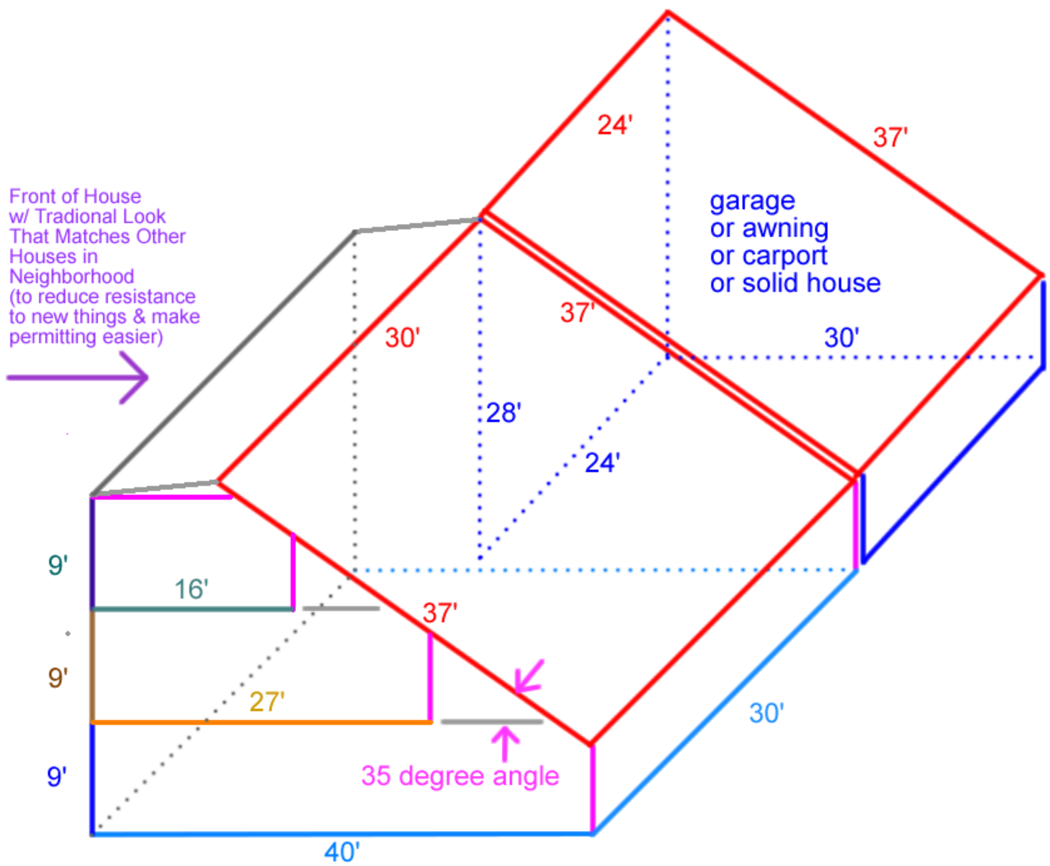


Chapter 11) Continuous 2K 35° solar over 3 Story House

The below drawing illustrates extending 1100sf house solar by 900sf to create one continuous rectangle of 2000sf. The additional piece (900sf) could be implemented with solar over aluminum framing. Also, one could integrate this with a garage, carport, awning, and/or patio.

If left side is house is front, and one builds a 28ft high wall in front of 900sf (24x37') that matches front of house, then that wall might be costly and visually confusing due to its 3 story height (i.e. a 3 story garage might appear goofy).

If the right side of the house is the front, then it might be visually appealing to see one solid big piece of solar from the front, provided it is well accented (and one likes solar). What accents? Accent lighting on solar panels? ZE architects can work on making front facing big solar more visually appealing.



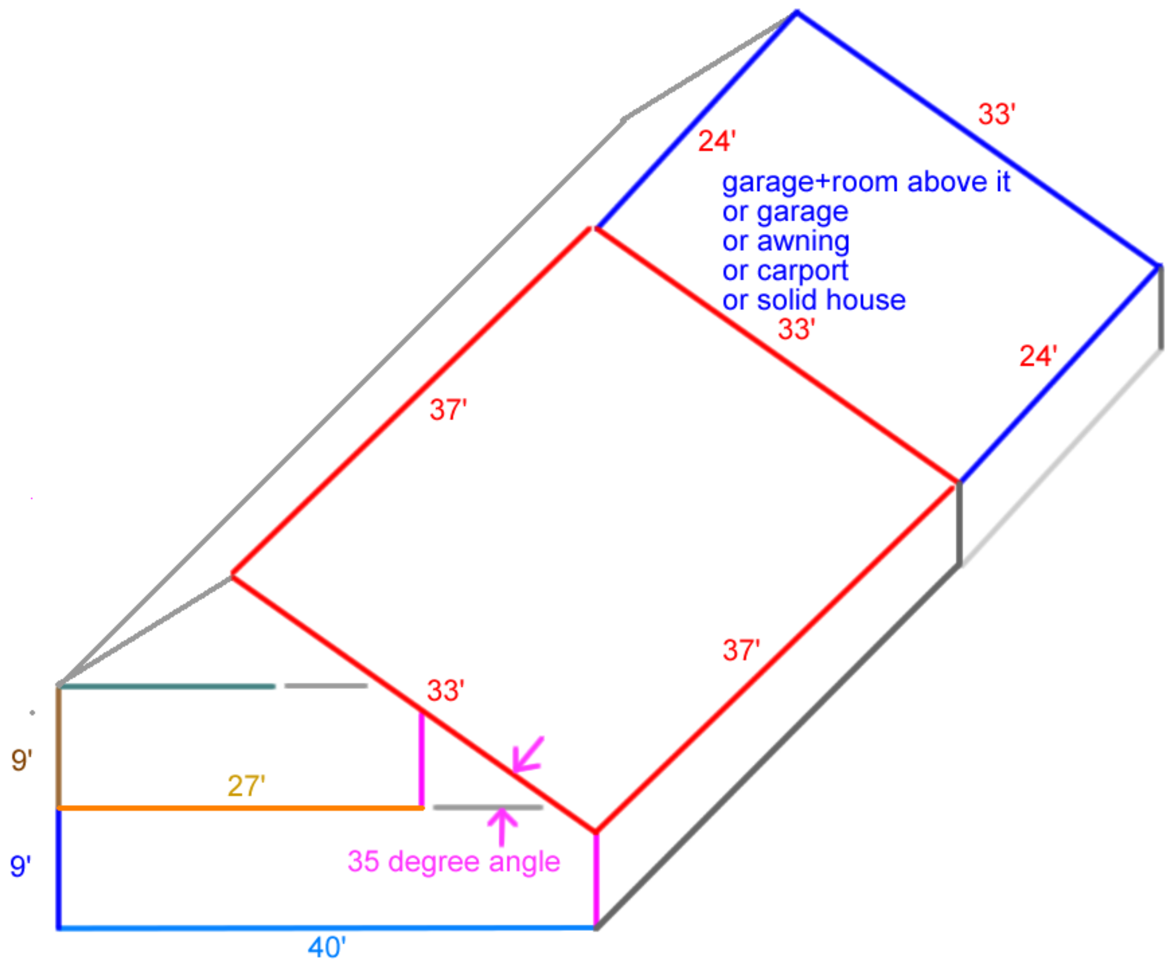
(16+27+40) = 83ft, discount 20% for non-usable space, this is 83*.8=66 total floor width (3 floors combined).

2000 indoor sqft / 66 width = 30ft length (depth in dwg)

37 * 30 = 1100 sq ft solar above main house

Add 900 (24 * 37) sq ft solar above garage (or carport) to get 2ksf total solar

The below drawing is similar to the previous drawing, yet it involves 2 stories instead of 3 stories.



(27+40) = 67ft, discount 20% for non-usable space, this is 67*.8=53 total floor width (2 floors combined).

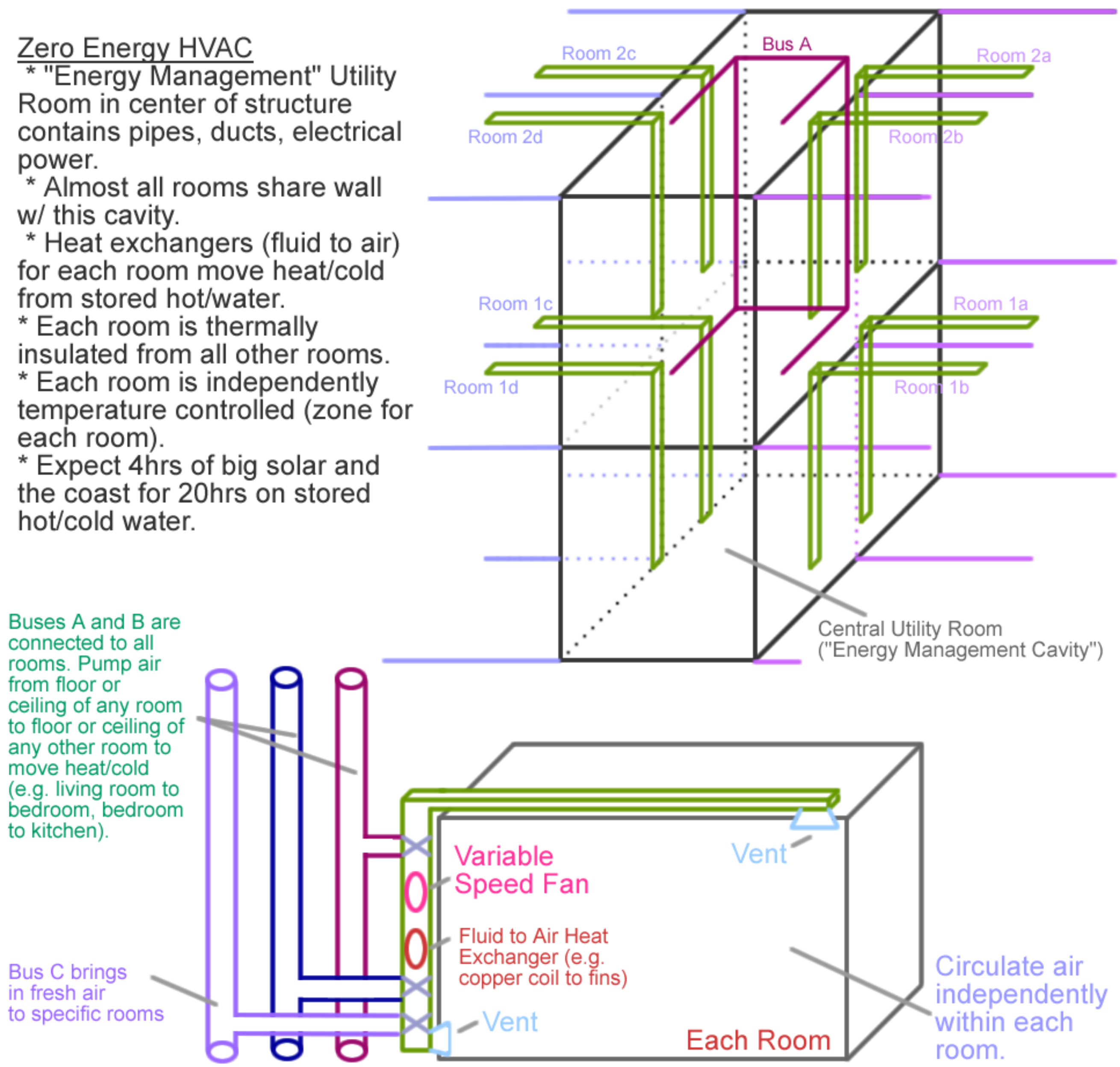
2000 indoor sqft / 53 width = 37ft length (depth in dwg)

37 * 33 = 1220 sq ft solar above main house

Add 780 sq ft (24x33) solar above garage (or carport) to get 2ksf total solar

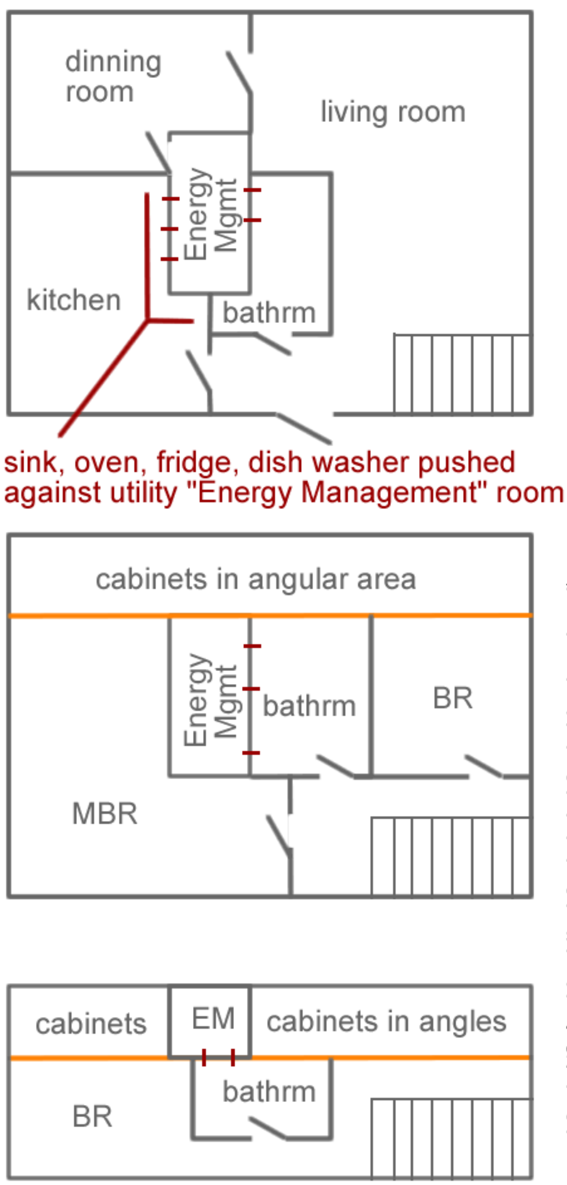
The HVAC system integrates solar panels, solar thermal storage (e.g. 500 gallons water), ground source heat pump and temperature zones for each room. We can expect 4 hours of big solar (30kW * 4 = 120kWhr) and then coast for 20 hours (e.g. 2kW through walls each hour * 24hrs = 50kWhr loss through walls given 15°Celcius outdoor air temperature).

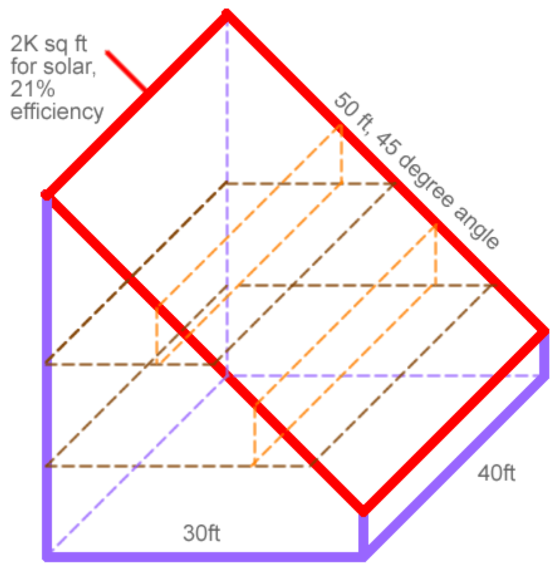
The temperature in each room is independently controlled, and one can move air from the floor or ceiling of one room to the floor or ceiling of any other room, as illustrated below (via busses A and B). Researchers test different schemes for moving energy between different rooms, from water storage tanks to rooms, from solar cells to water storage, and from a ground source (55°F) to structure.



Chapter 14) Example of Utility Room in Center of House

The below drawing does not meet our ZE1 requirements; however it does illustrate how one might position rooms around a central utility cavity on each floor, with an angled solar roof above.





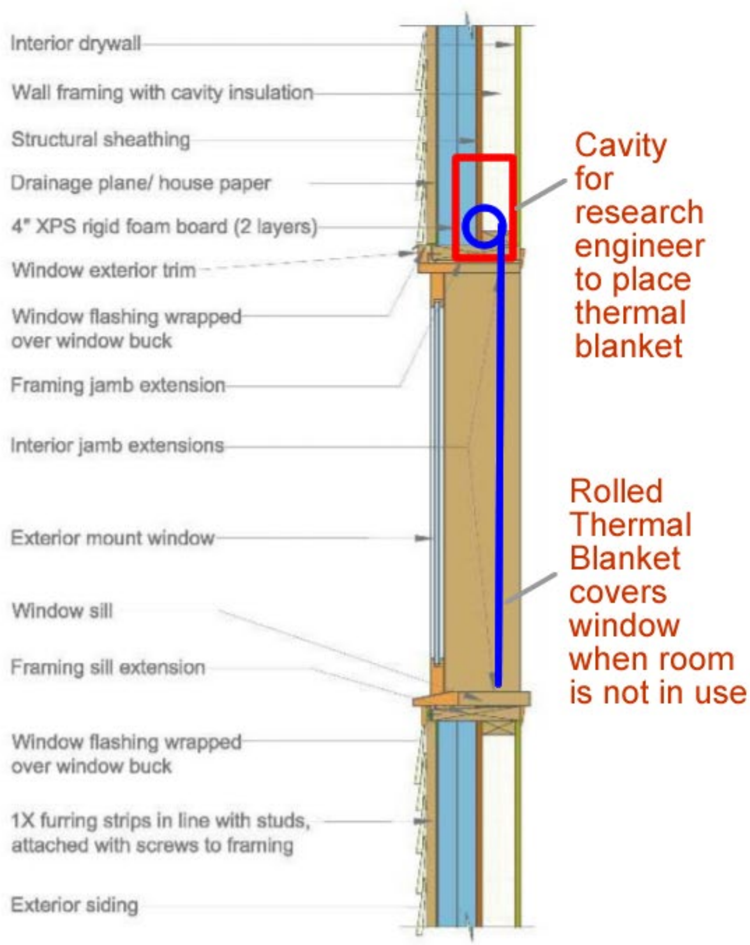
Project Design Requirements

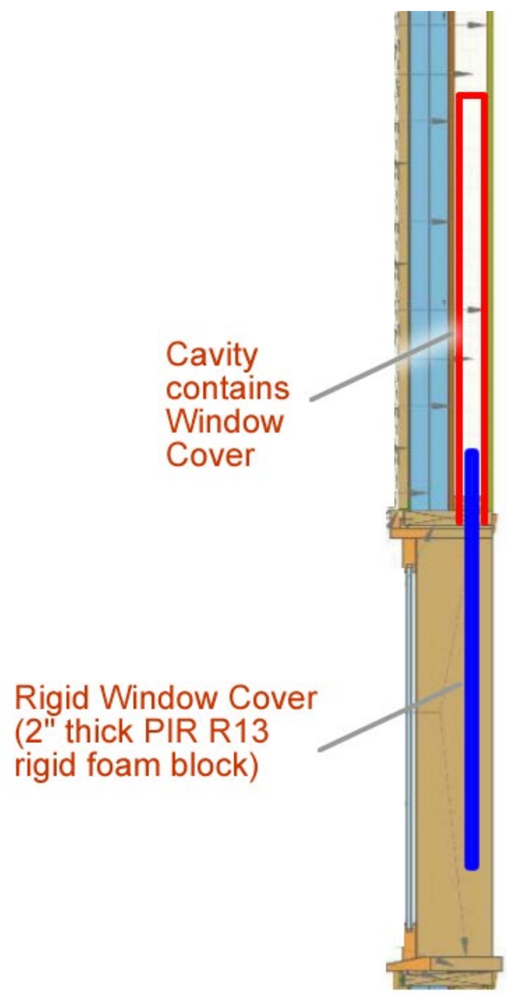
* Zero net energy consumption over one year without burning natural gas. Grid is used for storage.
* Comfortably support family of four during New England winter (i.e. many warm rooms).
* 2k sq ft floor space and 2K sq ft solar collectors at ~45degree angle pointed toward south, 21% efficiency, ~30KW.
* Each room is temperature zoned & internal walls are insulated.
* Ability to move air from floor or ceiling of one room to floor or ceiling of any other room.
* Store heat/cold for 20hrs via tank(s) of water.
* Occupancy detector in each room.
* Motorized thermal blanket on all windows.
* Rooms share wall with central Energy Management cavity which contains pipes, ducts, electrical cables.
* Energy appliances press against Energy Managment wall (i.e. sink, shower, toilet, oven, refridgerator, washer/dryer, dish washer).
* Researchers connect ground source heat pump to Energy appliances via central computer that controls/monitors all systems.
* Researchers route ~64 power cables with different voltages (e.g. 48,24,12, 6, 3,1.5V) from solar array to central switching station giving them ability to route different AC and DC voltage of different frequencies and amplitudes to each appliance, to optimize energy.
* Wires are routed from central area to all doors, windows and ceiling to support researchers.
* 1" x 16" x 7' cavities are created behind drywall to support research in vacuum insulation maintained by small pumps.

Chapter 15) Windows Laboratory

The window lab provides cavities for researchers to place motorized window covers that deploy when a room is not in use. Covers can either be inside or outside the window; and can either be rolled or solid block, as shown below. A 2" thick rigid foam block provides fantastic insulation and can easily sit in a cavity above a window (and/or below), especially within a thick wall (e.g. 8" to 12" total thickness). Conduit (pipe) connect cavities to utility room, enabling researchers to route wire to these locations.

Window manufacturers are often not truthful. A glass pane with R1 thermal conductivity stays at R1 even with an expensive coating. Coatings often help with heat radiation, yet not thermal conduction. Much heat is lost at windows -- covering with 2" thick PIR insulation (R13) would save much energy, especially with larger windows in a colder climate.





Chapter 16) Heat Math

The following shows how one can push energy from solar into hot water and then use this for house heating/cooling when the sun does not shine, without burning natural gas, in a cold climate. The below table does not take into consideration inefficiencies, and shows a cold scenario (25°F outside temp).

				typ 2ksf house	ze1	ze1 w/ 2" XPS on Windows
Temperature	Outdoor temp		F	**25**	**25**	25
	Room temp		F	**75**	**75**	75
	Room to Outdoor temp difference		F	50	50	50
	Room to Basement difference		F	**30**	**30**	30
House	surface area, exterior wall		sq ft	**2,520**	**2,520**	2,520
	surface area, roof		sq ft	**2,000**	**2,000**	2,000
	surface area, floor		sq ft	**1,200**	**1,200**	1,200
	surface area, windows		sq ft	360	160	160
	% of total		%	**18%**	**8%**	8%
Insulation	R rating, exterior wall		R rating	**16**	**40**	39.0
	R rating, roof		R rating	**40**	**80**	80
	R rating, floor		R rating	**12**	**50**	50
	R rating, windows		R rating	**2**	**4**	18
Energy thru Walls	energy tsfr, exterior wall		BTU/hr	7,875	3,150	3,234
	energy tsfr, roof		BTU/hr	2,500	1,250	1,250
	energy tsfr, floor		BTU/hr	3,000	720	720
	energy tsfr, windows		BTU/hr	9,000	2,000	444
	Doors & Etc btu/hr		BTU/hr	1,338	512	520
	% of total		%	10%	10%	10%
	energy tsfr, total	https://rin	BTU/hr	23,713	7,632	6,169
			kW	6.9	2.2	1.8
	walls energy loss over 24hrs		kWHr	167	54	43
			BTU	569,238	183,212	148,090
	walls energy loss over 1yr		kWhr	60,877	19,594	15,838
	> $ electricity		$	$ 9,132	$ 2,939	$ 2,376
Solar Array	Solar Array		kW	6	30	30
	energy when sunny		BTU/hr	20,472	102,360	102,360
	hrs/day of sun		hrs/day	4	4	4
	energy/day		kWHr/day	24	120	120
			BTU/day	81,911	409,556	409,556
Ratio of Solar Energy Generated to House Heating Consumed			ratio	14%	224%	277%
Pump Energy Into Water Storage (e.g. heat 500gallons by 80F)						
	% of solar into heating H2O		% of total		80%	80%
	Power into heating H20		kW		24	24
			BTU/hr		81,888	81,888
	heat pump tons	http://ww	tons		6.82	6.82
	Energy Pumped into Water		kWHr		96	96
Pull energy out of stored water			hours		20	20
Energy Stored in Water			gallons		500	500
	degrees heated during storage		F		80	80
	starting temp	energy (kHr) =	F		80	80
	final temperature	tempDiff(F) =	F		160	160
	energy stored in water		kWHr		96	96
Stored Water Circulates into Radiators inside ducts (one per room), 20hrs/day						
	energy from H2O to house heating		BTU/hr	23,713	7,632	6,169
			kW	6.9	2.2	1.8
	H20 temp cooling per hr		F/Hr		4.0	4.0

Manhattan 2

R&D to Create a Low Carbon Society

More Information

* Manhattan 2 Summary (2pgs): http://www.ma2.life/doc/plan/MA2_Summary_2pgs.pdf
* Five R&D Initiatives (3pgs): http://www.ma2.life/doc/plan/MA2_Five_R&D_Initiatives_3pgs.pdf
* Blueprint (180pgs): http://www.ma2.life/doc/plan/Manhattan_2_Blueprint.pdf

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