Case Study: Passive House Construction in Kansas City

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Abstract

The most effective way to reduce world energy consumption on our planet is to reduce the annual heating and cooling demands of our buildings. The combination of a super insulated, thermal bridge free, airtight building envelope design, integrated with high performance glazing units, can reduce annual heating and cooling demands by over 90% and reductions of 60-70% in overall energy consumption compared to traditional design methods. Our firm is designing and building a single detached Passive House in the Kansas City urban core that will achieve such reductions in energy consumption without the use of solar panels nor geothermal. This is a spec home, and is set for ground breaking in the first quarter of 2015. The interior air will be conditioned with an air- to-air heat pump and annual heating demand is modeled to be 4.75 kBTU/ft^2·yr and the annual cooling demand to be 3.25 kBTU/ft^2·yr. A typical home in Kansas City would have an annual heating demand of 42.75 kBTU/ft^2·yr. This will be one of the lowest energy consuming homes in the Midwestern region of the United States.

1. Home Design Specs

The home is located in the Rosedale neighborhood of Kansas City, Kansas. This is an urban infill site that is 5 miles from downtown and ½ mile from University of Kansas Medical Center.

- 3-bedroom, 2-bathroom
- Two-story with half in-ground basement
- 2400 square feet of interior area and 2250 of treated floor area (TFA)
- Envelope area to interior floor area ratio is 2.4

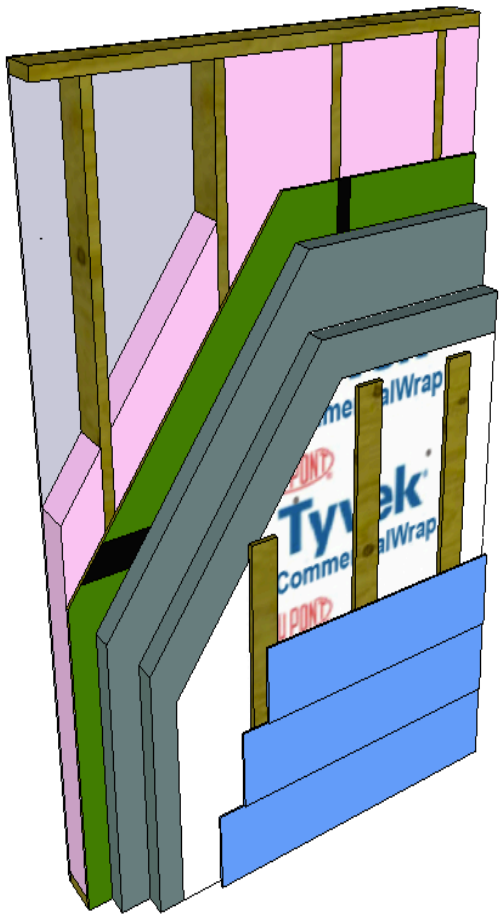
2. Location & Climate

- ASHRAE Climate Zone 4
- Mixed Humid Climate
- Heating Degree Days (Base 65F): 5493
- Cooling Degree Days (Base 65F): 1346

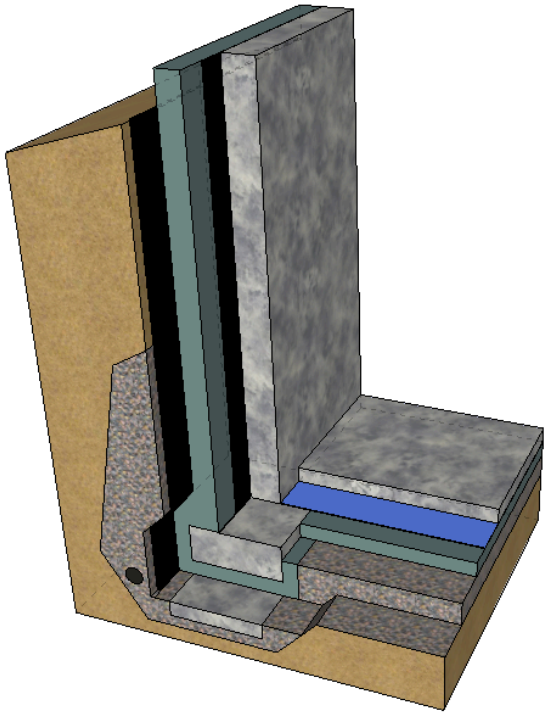
3. Envelope Design

The following describes the envelope components of the home. The exterior wall, foundation and roof are reviewed. The connections between the air barrier materials are described, along with the thermal resistance layers.

- Wall: 3 ½" Fiberglass batt insulation with 6" of exterior Type I EPS (R-36 Clear wall)
- Roof: 20" Blown cellulose (R-76 Clear wall)
- Below grade foundation: 6" Type II EPS (R-23 Clear wall)
- Basement slab: 4" Type II EPS (R-17 Clear wall)
- Window: Triple pane (R-7)
- Anticipated air tightness: $ACH_{50} < 0.6$



Exterior Wall: The exterior wall is a 2x4 single wall construction with exterior applied foam insulation. The primary air barrier is the structural sheathing with taped seams. The sheathing is made continuous on the underside of the roof trusses and the sheathing is taped to the foundation wall to ensure a continuous air barrier. Thermal resistance is provided by stud cavity batt insulation and two 3" layers of exterior applied expanded polystyrene foam. The seams are offset to avoid a continuous void in the foam when it begins to shrinks over time. Vertical furring strips are attached back to the structural studs, and the exterior cladding is installed with a rain screen.



Foundation System: The foundation system is a full height basement. There is continuous insulation under the slab with 4" type II EPS. Under the footing, the insulation is made continuous with GeoFoam grade EPS at 4" of thickness. On the exterior side of the foundation wall, 6" of type II EPS is installed. This thickness is used to allow a smooth transition of insulation thickness from the exterior wall to below grade. All below grade foam insulation contains termite proof additives. The air tightness layer is made continuous with a layer of polythyelene between the slab and EPS foam and is attached to the foundation wall. The vertical concrete wall is the airtight layer, and is made continuous with the exterior sheathing using a flexible tape. The foundation wall is sprayed with a water damping membrane, and then a waterproofing membrane is applied on the exterior side of the 6" EPS.

Windows: Windows and shading strategies are critical components to the envelope system. Southern windows have a larger SHGC to generate more solar gains, and the other orientations have lower SHGC values, with higher R-values.

Window PHPP input values:

Orientation	*SHGC*	*U-Value (cog)*	*R-Value (cog)*
Southern Windows:	0.61	0.11	9.09
N/W/E Windows:	0.39	0.09	11.11

Window energy balance:

Orientation	*Area [ft²]*	*Transmission Losses [kBTU/yr]*	*Heat Gains Solar Radiation [kBTU/yr]*	*Balance [kBTU/yr]*
North	31	1065	207	858
East	23	451	235	216
South	97	2399	4474	2075
West	45	868	524	344
Totals	***196***	***4783***	***5441***	***658***

4. Mechanical Design

The conditioned air and ventilation air streams are separated with two systems. Each system is described separately in the following. The systems are separated to make for easier installation and commissioning of the units.

Conditioned air: The primary source for conditioned air is a ducted mini split heat pump. The condenser is a 24 000 BTU unit, and the evaporator heads are two 9 000 BTU concealed, ducted units. Although the design peak load is under 10 kBTU for both heating and cooling, a larger condenser is the smallest available that still runs two ducted units. Two evaporators are used because it allows for better distribution of conditioned air between the rooms. A simple wall mounted evaporator was an option, but concerns about the conditioned air reaching all the rooms, especially during the cooling season, turned the design towards a ducted mini split system.

Short duct runs are used, so each evaporator can deliver conditioned air to multiple rooms. The duct runs are similar in length to that of duct runs for a range hood vent or a bathroom vent: 6-10 feet with minimal turns. The ducts are insulated and sealed to ensure the conditioned air reaches its destination.

Ventilation: Ventilation air is separated from the conditioned air and is supplied with an energy recovery ventilator. Fresh air is supplied to the bedrooms and living spaces, and the stale air is exhausted from the bathrooms, kitchen and laundry room. Both air stream volumes are balanced and the ERV runs consistently throughout the year. The ducts from the unit to the exterior are insulated to maintain efficiency ratings and to prevent condensation.

5. Construction Costs

Appliances	$ 7,000
Bathroom vanities	$ 2,000
Carpet	$ 2,132
Countertops	$ 4,510
Drywall	$ 12,335
Engineering fees	$ 1,200
Electrical, fixtures & monitoring system	$ 16,000
Excavation, flatwork & foundation	$ 29,350
Framing & lumber	$ 66,800
Hardwood flooring	$ 10,800
HVAC systems	$ 13,000
Insulation	$ 16,000
Painting interior & exterior	$ 10,500
Job site supervision & maintenance	$ 6,000
Millwork for cabinets & trim	$ 24,000
City permit	$ 1,500
Third party certification (QA/QC)	$ 3,000
Plumbing & fixtures	$ 17,000
Roofing	$ 7,000
Exterior stonework	$ 3,500
Windows & exterior doors	$ 20,250
TOTAL	$ 273,877
Profit & Overhead (10%)	$ 27,387
TOTAL COST	$ 301,264 / 2400 SF = $ 126/SF