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Establishing Priorities for the Design of Affordable, Environmentally Responsible Housing in Dallas, Texas, a Mixed Climate Zone

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Betsy Pettit, AIA and Joseph Lstiburek

Abstract:

Twelve affordable, healthy, environmentally responsible single family houses were designed and built on an urban infill in Dallas, Texas. They will sell for under $80,000 each, making them affordable to families earning less than 80 percent of the median income in the Dallas metropolitan area (under $35,000). Monthly payments will range between $500 to $700 per month. Utility costs (heating, cooling, and hot water) are expected to be $30 per month. Typical utility costs for houses of similar size in Dallas have ranged Between $80 and $100 per month. The building system design resulted in a 60- to-70 percent reduction in energy consumption. A minimum of $50 per month for utility cost will be saved.

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Betsy Pettit, AIA
Joseph Lstiburek, P.Eng.

Introduction

Twelve affordable , healthy, environmentally responsible single family houses were designed and built on an urban infill in Dallas, Texas. They will sell for under $80,000 each, making them affordable to families earning less than 80 percent of the median income in the Dallas metropolitan area (under $35,000). Monthly payments will range between $500 to $700 per month. Utility costs (heating, cooling, and hot water) are expected to be $30 per month. Typical utility costs for houses of similar size in Dallas have ranged Between $80 and $100 per month. The building system design resulted in a 60 to 70 percent reduction in energy consumption. A minimum of $50 per month for utility cost will be saved.

The two story 1273 sq. ft. houses are arranged around two central green spaces with service corridors in the back for parking and trash pick-up. Each house lot contains approximately 1900 sq. ft. and includes parking for two cars as well as over 800 sq. ft. of outside space. This project achieves a density of 15 units per acre while being compatible with existing neighborhood housing. Sunlight brightens courtyards and other outside spaces such as uncovered balconies and covered porches for the majority of the day during a majority of the year. Windows and doors are placed to allow maximum natural light and ventilation. Unwanted summer solar gain is held to a minimum by avoiding window placement on the southwest elevations, selective use of overhangs, and selective placement of deciduous trees.

The building enclosure was designed with an exterior air retarder system to achieve maximum air tightness (1.5 square inches of leakage area per 100 sq. ft. of building enclosure surface area). Low envelope leakage and high insulation levels allowed for a low flow air distribution system. The floor trusses were used to create a floor plenum distribution system. The low heat gain and loss figures meant a small geothermal heat pump unit could be used for heating, cooling and hot water production. A simple and inexpensive controlled ventilation system was designed that allowed control of air pressure differences throughout the year .

The Priorities

Sustainability is generally defined as a commitment to meet our present needs without compromising the ability of future generations to meet their needs. As team members of a building development project, we have a responsibility to help

ensure a sustainable development. The effects of building development on the environment are:

1. The creation the interior environment in which people must live and work.

2. The expenditure of huge amounts of natural resources (many of which are not renewable)

3. The creation of a machine that continues to need to be fed (energy is needed to run a building).

The effects of building development on the environment are at the most basic level about ***durability***. Building a house or community is really about the durability of people (health, safety, and well being of people), the durability of buildings (the useful service life of a building is typically limited by its durability), and the durability of the planet (the well being of the local and global environment) . ***Durability*** is really another way of expressing the concept of ***sustainability*** to the building community.

When we build a building, a system is created that is an interaction of people, buildings and the environment. Making decisions about buildings requires prioritizing to reconcile the various needs of people, buildings and the environment. For example consider the needs of the people before considering the needs of the building. Consider the environment created by a building before considering the planetary environment. Resolve local concerns before resolving global concerns.

Goals

1. Create buildings that ensure a healthy environment for its occupants thereby promoting health for future generations.

2. Deliver buildings that are durable (life expectancy of 100 years with only minimal replacement of parts needed) thereby reducing future waste and depletion of natural resources.

3. Deliver that have a low total energy consumption during their lifetime. They must have a low operating energy since operating energy account for 60% to 70% of total energy consumption (Total energy = operating energy + embodied energy + decommissioning energy).

Design Priorities

1. Health and Safety: Exclude pollutants from conditioned spaces by:

- selecting, installing, operating and maintaining heating, cooling and ventilation equipment appropriately
- controlling the air pressures between the conditioned and unconditioned spaces as well as between rooms and interstitial spaces
- selecting appropriate building materials and installing and maintaining them correctly
- maintaining buildings in an appropriate manner and selecting appropriate housekeeping practices

Operate buildings so that pollutants are removed from conditioned spaces. Use controlled mechanical ventilation to accomplish this. Construct building enclosures and mechanical system duct work in a leak free, tight manner to control air pressure differences, thereby excluding environmental pollutants.

2. Comfort: Create comfortable buildings with respect to temperature, humidity, odors, sound/vibration and light by:

- using thermal insulation
- selecting efficient space conditioning systems
- designing and building leak free building enclosures and mechanical system duct work
- providing controlled mechanical ventilation and exclusion of pollutants
- selecting efficient glazing systems and using natural lighting
- operating buildings correctly and maintaining and cleaning them appropriately

3. Affordability: Create efficient buildings with respect to their use of energy, water and materials by:

- designing buildings that are efficient in their layout and use of interior space
- using thermal insulation to reduce operating costs
- selecting efficient space conditioning systems, equipment and lighting
- selecting efficient glazing systems
- providing controlled ventilation
- controlling the building envelope air leakage
- selecting appropriate materials
- constructing, operating and maintaining buildings in an appropriate manner.

4. Useful Service Life: Build durable buildings. Accomplish this by:

- preventing buildings from getting wet during construction
- allowing wall assemblies to dry should they get wet (sometimes referred to as a "forgiving" assembly) during construction and/or operation.

5. Environment: Build and operate buildings with a minimum of waste. Select materials and sites with respect to their local and global impact. Accomplish this by:

- reducing additional underground utility development by choosing sites with underground utilities in place
- recycling inner city infill sites when possible
- reducing construction water
- reducing operating water
- recycling construction waste
- recycling operating waste
- controlling soil erosion during site preparation and construction
- infiltrating storm water back into site
- controlling air pollution during construction and operation
- avoiding ozone depleting materials and systems
- using materials from managed forests and managed mineral extraction and processing
- reducing operating energy
- reducing embodied energy

Aesthetics: Design buildings that inspire a sense of community and participation by the occupants. Accomplish this by:

- creating traditional neighborhood patterns
- respecting and duplicating existing patterns where appropriate
- creating sufficient detail at eye level so that the occupants can see and touch
- choosing colors and textures that harmonize with the local environment

The Design Approach

The Esperanza del Sol development applies the basic principles of healthy housing, resource efficiency, and energy conservation.

1. To provide healthy housing, the following strategies were used:

- source control of pollutants by pressurizing the building enclosure and minimizing the exterior humidity gain
- source control of pollutants by using low VOC off-gassing materials
- dilution of interior pollutants with a controlled mechanical ventilation system designed and operated to meet ASHRAE 62 - 1989
- production of an owners manual describing healthy housekeeping and maintenance practices

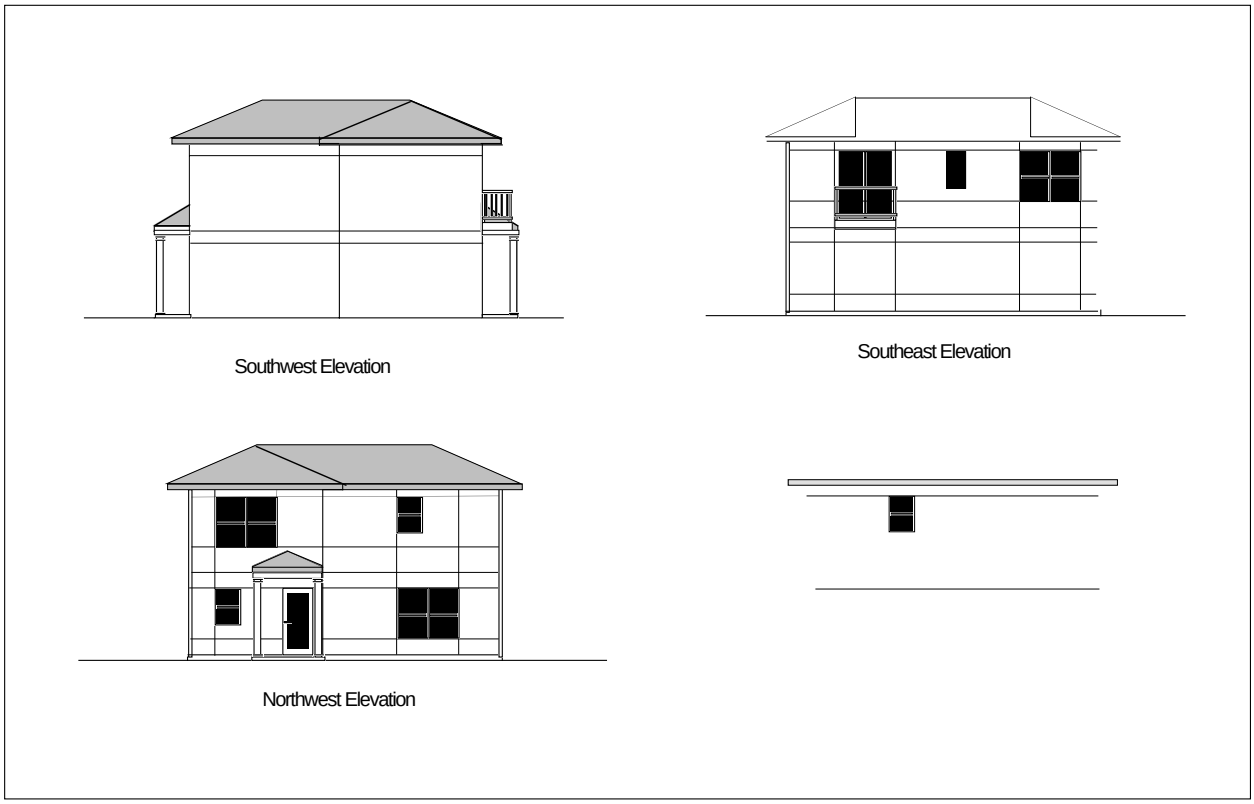
2. To provide resource efficiency the following strategies were used:

- durable construction by designing a forgiving building enclosure design, with high drying potential that requires minimal maintenance
- minimization of site waste by use of pre-manufactured components (floor trusses doubling as air distribution systems) and standard material sizes
- use of recycled materials such as cellulose insulation carpeting made from recycled milk cartons, and recycled ceramic tiles in the bathrooms made from recycled windshield glass
- use of manufactured wood products such and finger-jointed studs (carbon storage within a durable envelope) from agricultural forestry (fast growing trees, wood chip waste, scrub growth)
- efficient use of wood products (Optimal Value Engineering framing techniques)
- low operating energy use (high energy efficiency)

3. To provide for energy conservation the following strategies were used:

- natural day lighting opportunities were optimized (at least one and usually two windows are located in each room)
- passive heat gain was used were possible (rooms on the southeast side of the houses were designed to allow for the optimal window placement for solar heat gain)
- outside spaces were sited to have sun for the majority of the day (these spaces include the courtyard area, uncovered balconies, and porches on the southeast side of the building)

- interior layout and window placement were designed to allow for maximum natural ventilation
- overhangs were provided to protect from summer overheating
- deciduous trees were positioned to protect asphalt and houses from summer overheating
- a stand of existing trees on the northwest perimeter of the site provides protection from cold winter winds
- elevated levels of insulation to increase the thermal resistance of the building enclosure
  - walls: R - 25
  - roof: R - 38
  - perimeter insulation: R - 5
  - band joist coverage at plenums: R - 30
- airtight construction was achieved with an exterior wall air barrier system (stucco walls) - 1.5 square inch leakage per 100 square feet of enclosure surface area
- controlled mechanical ventilation meeting ASHRAE 62-2989
- efficient mechanical systems for cooling, heating and DHW SHEER rating for cooling at 12.0 (geothermal heat pump system with heat recovery for hot water)
- airtight, pressure tested distribution system (no duct leakage) maximum pressurization depressurization limit of 3 Pascal, all ductwork enclosed in a conditioned space
- OVE framing minimizing sq. ft. of wood framing acting as a thermal bridge from the inside to the outside as well as increasing the area available for full insulation
- blown cellulose wall insulation was used to eliminate installation caused thermal defects common with batt insulation
- double glazed thermally broken window units, insulated exterior doors



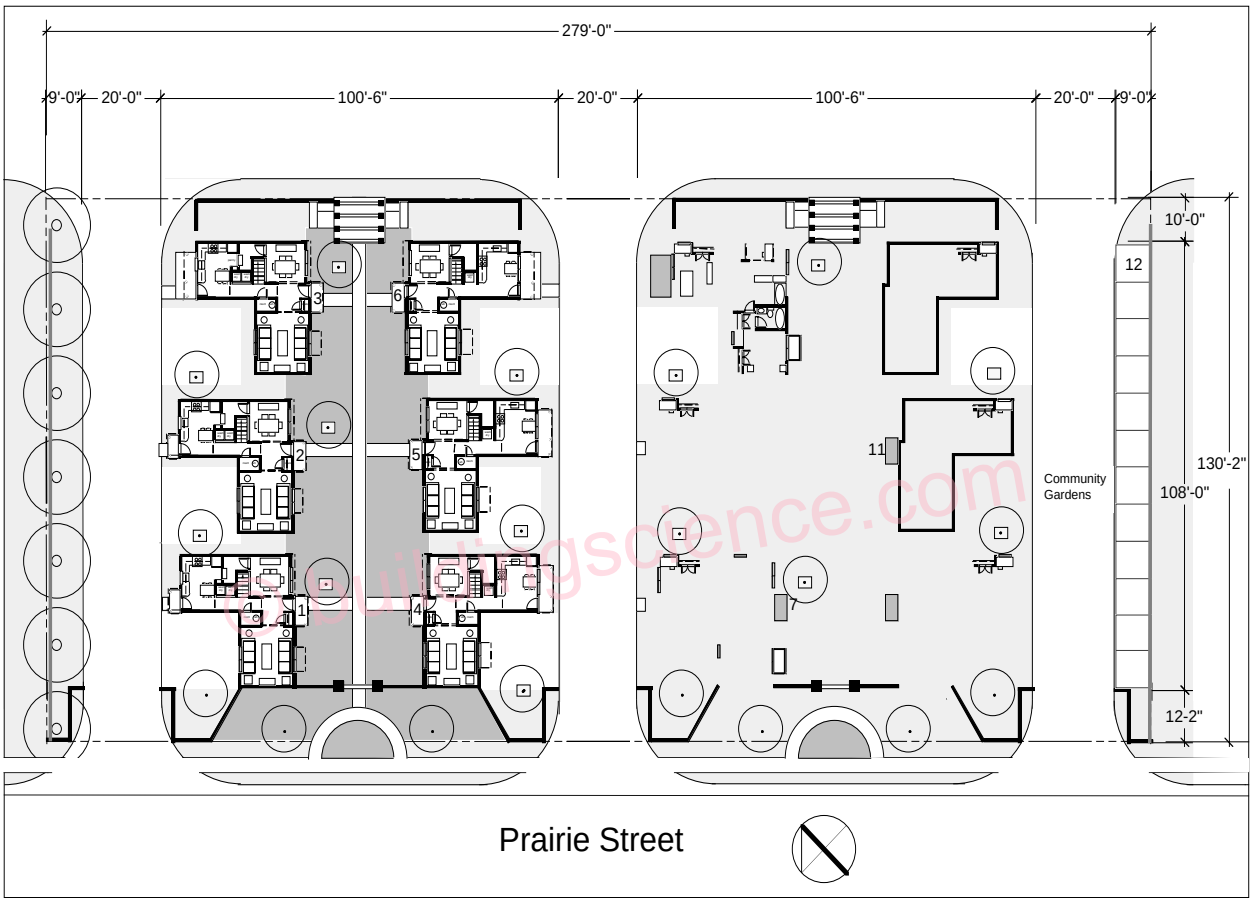
The Development Process

1. Site selection:

    - an existing inner city infill site was chosen
    - the site has existing utilities and infrastructure in place
    - the site was located on existing public transportation routes

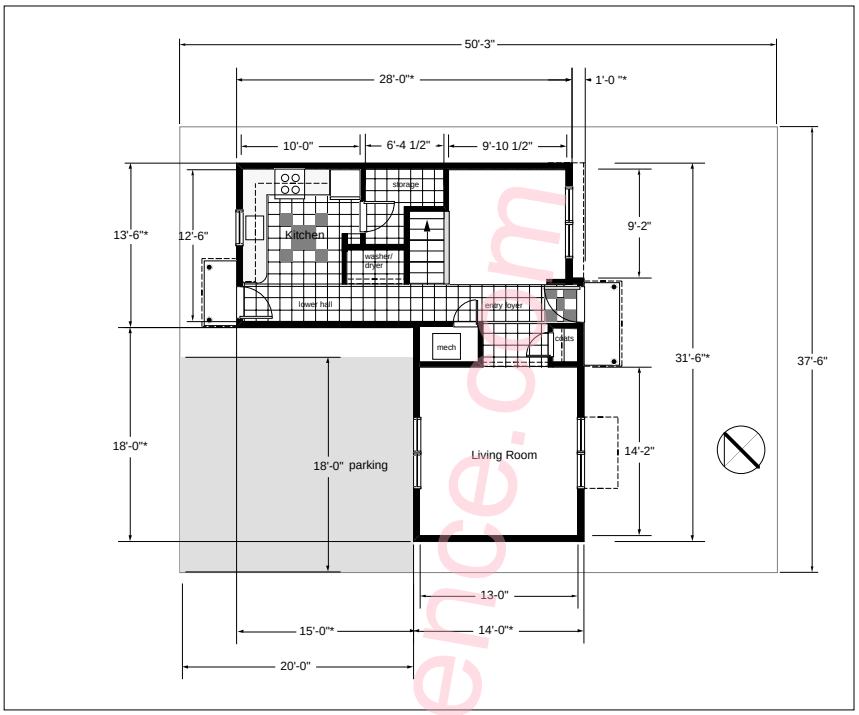
2. Site layout:

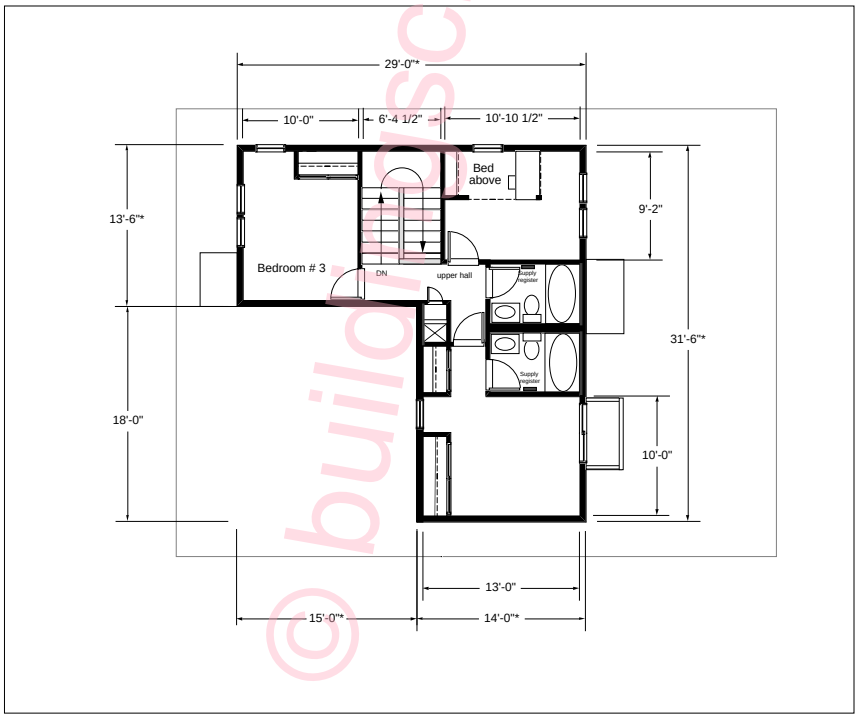
    - the buildings were oriented to take advantage of passive solar heating while respecting existing neighborhood layout patterns
    - sun angles from both winter and summer conditions were analyzed to make sure that outside public areas and outside private spaces were sunny and inviting
    - buildings were laid out to take advantage of natural ventilation
    - the site was laid out to create primary greenspaces (courtyards) for people and secondary service alleys for cars and garbage pick-up
    - a density of 15 units per acre were created while giving each home owner their own semi-private space
    - the primary greenspaces were connected visually to the neighborhood by a recessed opening with gateposts, yet separated for security reasons from the neighborhood by the use of a perimeter site wall
    - care was taken to respect existing zoning and building regulations while minimizing paving and parking



3. Floor plan design

- the layout of the houses used space in an efficient manner
- single family detached houses were designed so that parking and usable outside space were possible on a 1900 sq. ft. lot area
- windows were located to take advantage of solar gain in the winter
- windows and exterior envelopes were designed to be protected from summer heat gain





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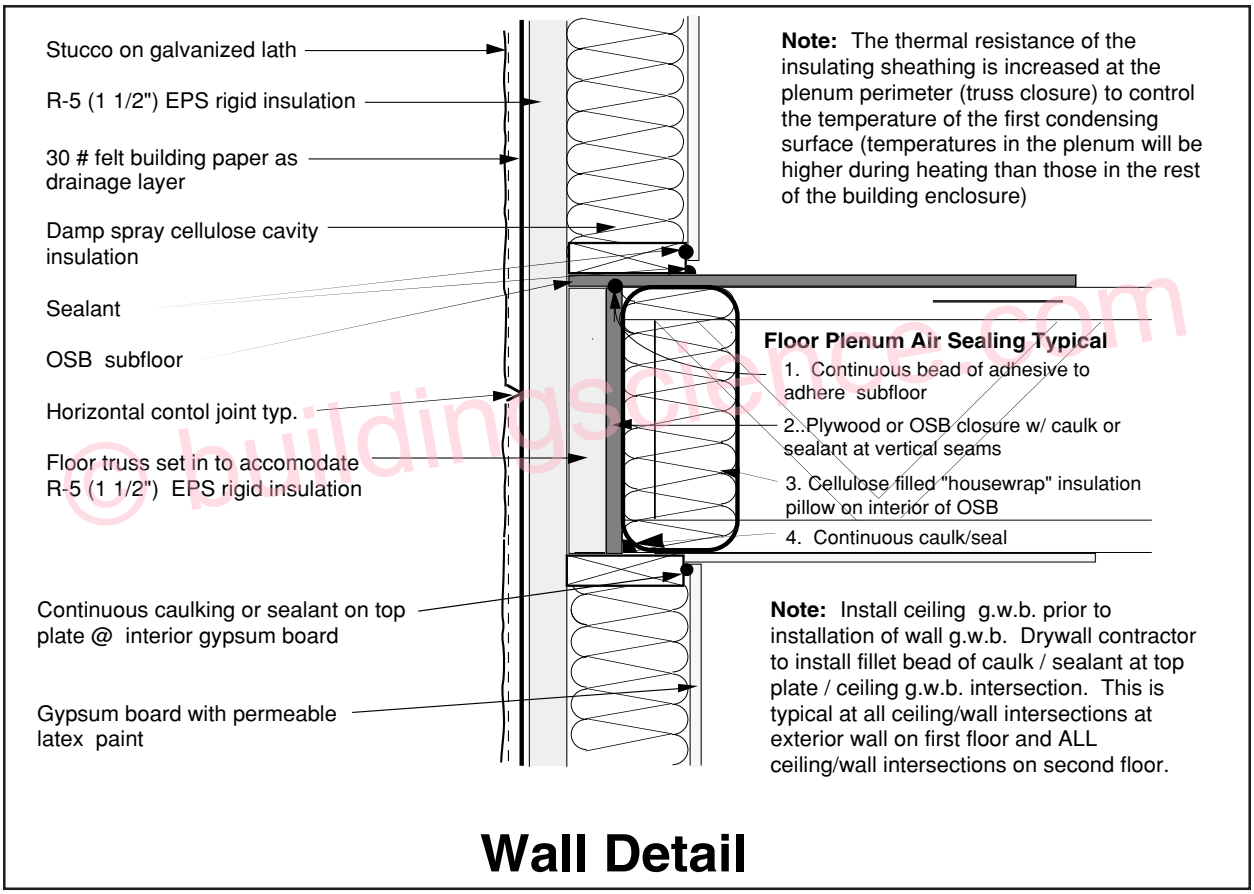

Wall Detail

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4. Envelope Design

The following figures are based on a house with a 630 sq. ft. footprint (and ceiling), 120 liner feet of perimeter, and 2040 sq. ft. of exterior wall.

- Fenestration

The total sq. ft. of fenestration (glazing) is approximately 10 percent of the wall area and 16 percent of the floor area. Fenestration equal to 10 percent of the floor area faces southeast. Sixty-three (63) percent of the total glazing has a direct solar aperture.

- Framing

Changing from 2x4 @ 16 inch o.c. to 2x6 @ 24 inch o.c. OVE framing with floor trusses resulted in no added costs. With fewer pieces to install, it involved less labor. OVE framing is more energy efficient than standard framing by approximately 15 percent, due to less thermal bridging. Also, from a resource efficiency point of view, fewer materials were required.

- Cavity Insulation

Changing from 3.5 inches of wall cavity insulation to 5.5 inches of wall cavity insulation cost an additional $200.00. This cost is so low because the extra space is free (from the OVE framing). The only cost is for the insulation, not the extra wall framing.

- Exterior Sheathing

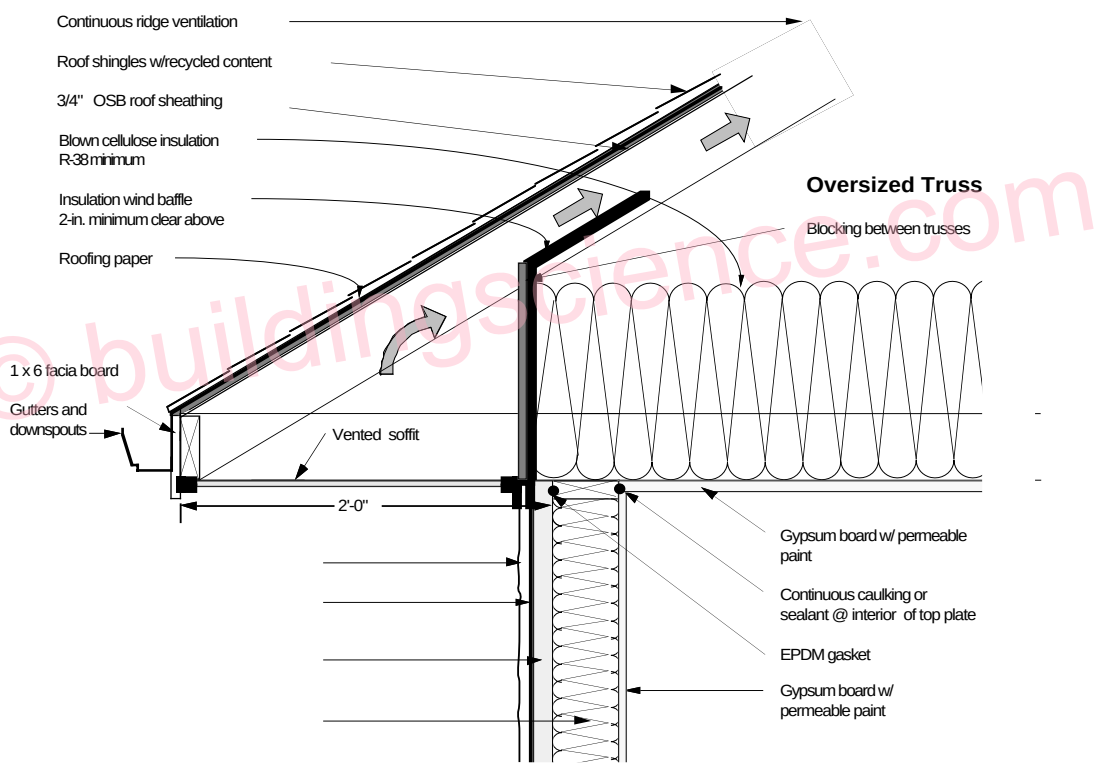
Changing from foil faced cardboard sheathing (thermoply) that has no effective thermal resistance to 1.5 inches of EPS (R-5) cost an additional $300 and eliminated the need for an interior vapor diffusion retarder. The use of an insulating sheathing raises the temperature of the temperature of the first condensing surface so that the interior vapor retarder is no longer necessary. The elimination of the interior vapor retarder allows the wall assembly to dry to the interior, creating a forgiving wall assembly. The high drying potential (to the interior) of this wall assembly allows the use of damp spray cellulose.

- Cellulose Insulation

Adding an extra 2.5 inches of cellulose insulation (to go from R-30 to R-38) cost an extra $50 per house.

- Perimeter Foundation Insulation

Adding R-5 (2 feet wide/deep) cost $60 for the insulation and $65 for the protection membrane. It took one man one hour to install the insulation and two men one hour to install the membrane for a total labor cost of $75. The total cost of this upgrade was $200.



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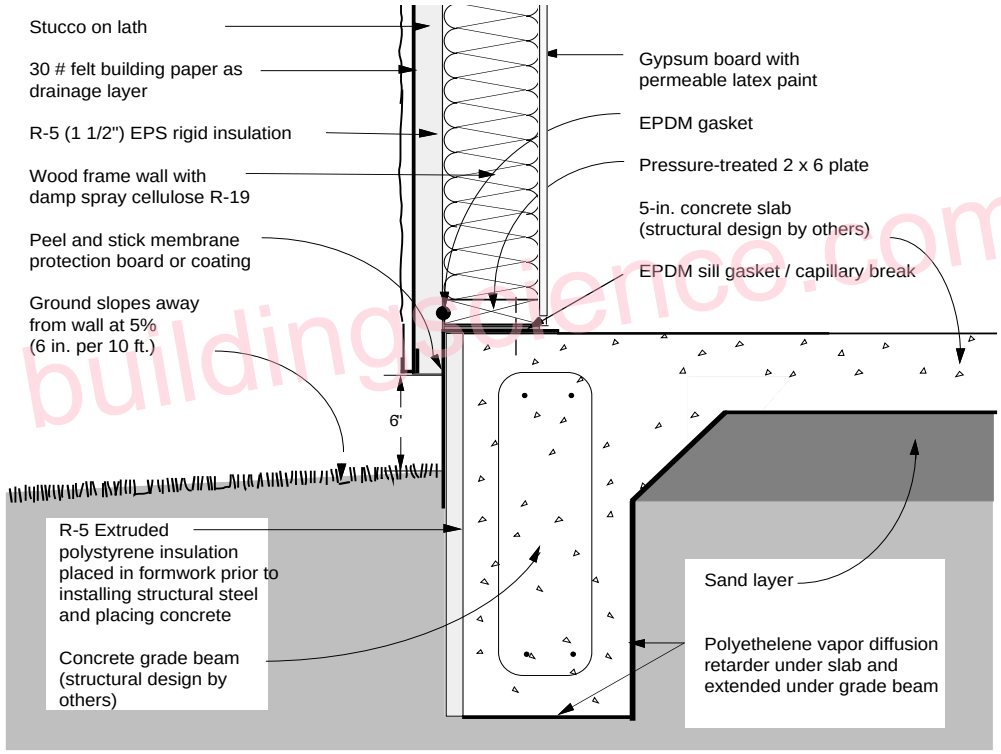
Roof Overhang Detail



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- Rain water is controlled by gutters and downspouts, and grade sloping away from the building.
- Capillary suction is controlled by sheet polyethelene under the slab and the rigid insulation on the perimeter of the grade beam.
- Air movement into the conditioned space is controlled by sealing the bottom plate of the exterior wall to the slab.
- Vapor diffusion from the surrounding soil is controlled by polyethylene sheet installed under the slab.
- Slab penetrations sealed to control air movement and vapor diffusion.
- Insect control occurs through the use of the peel and stick membrane thermoset to the concrete.

Foundation Detail

- Air Tightening

All the gaskets, caulking and sealants cost an extra $400 per house. The cost of installing this was about 4 hours for one man or $100. The total cost of this upgrade was $500.

5. Heating/Cooling System

Three heating/Cooling systems were evaluated for this project.

- Gas hot water heat with electric high efficiency electric air conditioning
  First cost - $3150/unit
- Air-to-air integrated heat pump units
  First cost - $3533/unit
- Geothermal heat pumps with air conditioning and hot water assist
  First cost - $2992/unit (with utility rebates)

The geothermal heat pump unit provided the best first cost to the project.

Cost Summary of the Building Enclosure and Heating/Cooling System Upgrades

The extra insulation in the ceiling, walls, foundation perimeter, and the extra air tightening cost an additional $1,250. By making these upgrades, the floor plenum can be used as an air distribution system instead of buying and installing sheet metal duct work. A low flow floor plenum air distribution system was made possible by the significant increase in enclosure tightness and thermal resistance. Low flow air plenum air distribution system have consistently not worked in leaky building envelopes with low thermal resistance.

The significant increase in enclosure tightness and thermal resistance also led to a substantial reduction in the size of the heating and cooling equipment. Common payback calculations do not consider the extra advantage of the enclosure tightness and thermal resistance increase provides for the reduction in the size of the heating/cooling equipment and the ability to eliminate/reduce the need for traditional sheet metal distribution systems.

A smaller air conditioning load reduced the cooling requirements by one ton (the air conditioning system is one ton smaller than the typical installation for this area in a house of this size). The reduction in sheet metal work saved $750 and the one ton cooling that was not necessary saved $1000.

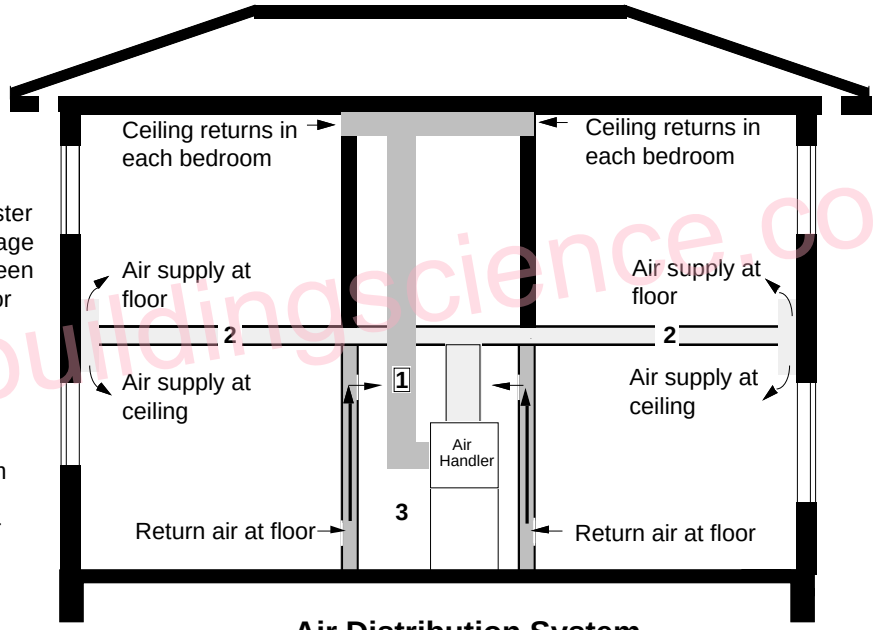
By the design team's calculations, the energy saving features of the enclosure and heating/cooling system have saved $500 per house.

NOTES:

1 - Balancing register controlling percentage of return flow between first and second floor

2 - Voids in floor trusses used as supply plenum

3 - Mechanical room acting as return plenum for first floor



Air Distribution System

- The first floor has high supply and low return
- The second floor has low supply and high return
- The low flow floor plenum air distribution system relys on a tight building enclosure and high levels of thermal resistance to function within acceptable comfort parameters

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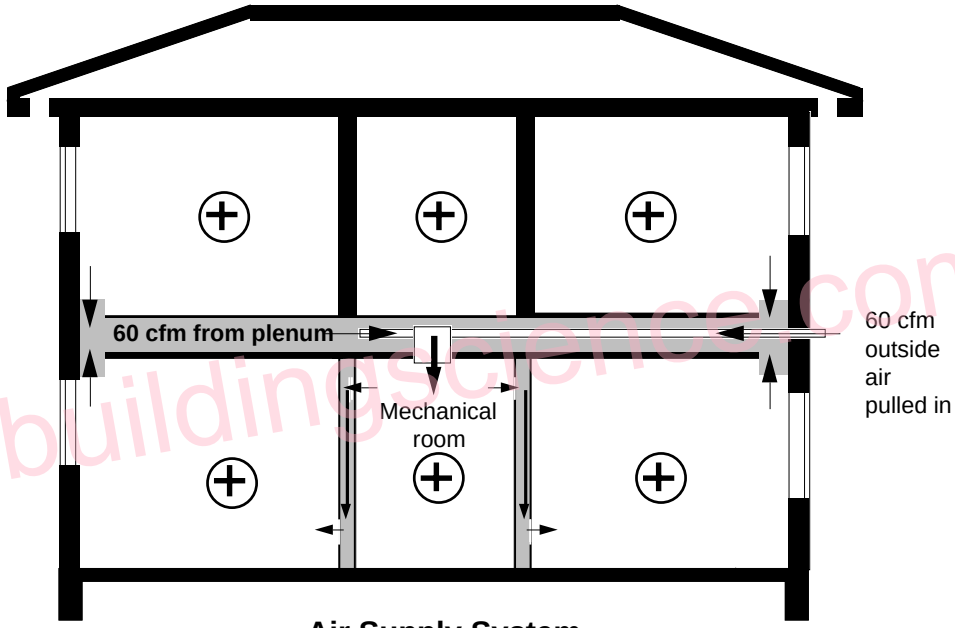

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Air Supply System

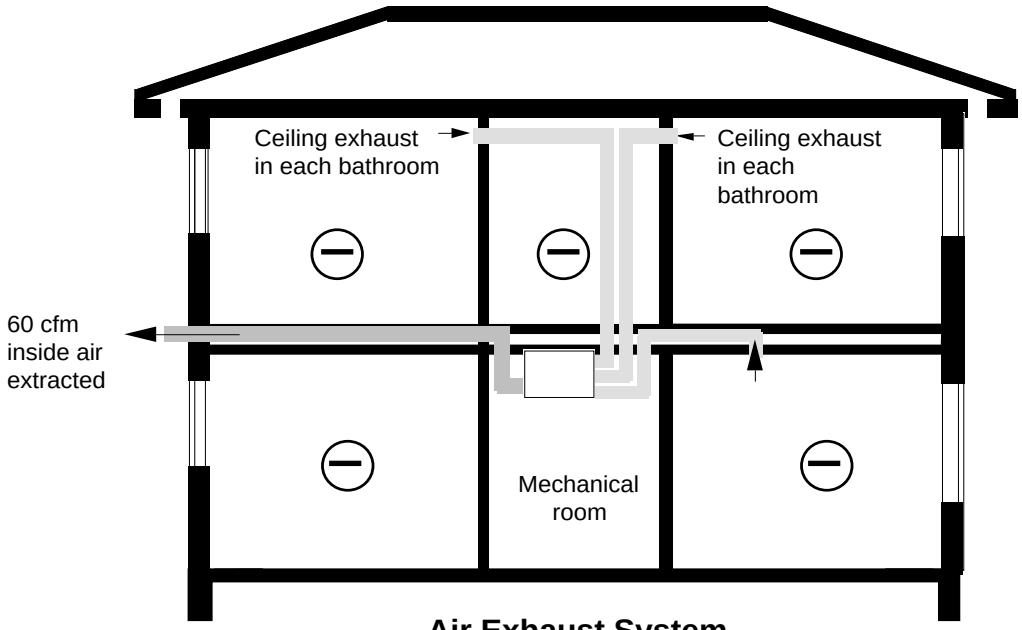
- 60 cfm of outside air supplied to building continously during cooling periods via a fan acts to pressurize the house
- the 60 cfm of outside air is mixed with 60 cfm of air from plenum to condition the exterior hot, humid air prior to introduction to the mechanical room
- when air handler is operating, flows reverse in the floor plenum and mechanical room, however, the building enclosure remains pressurized

6. Ventilation system

- a Rosenburg supply fan was used to pressurize (approx. 3 pascals) the building when cooling is taking place
- a Quietvent central exhaust system was used to depressurize (approx. 3 pascals) the system when heating is taking place
- the geothermal heat pump unit has a heating and a cooling setting that must be manually switched by the home owner between seasons
- when the home owner flips the switch to heating they will also be turning off the Rosenburg supply fan and turning on the Quietvent exhaust fan
- when the home owner flips the switch to the cooling they will also be turning the Rosenburg supply fan and turning off the Quietvent exhaust fan off
- the Quietvent exhaust fan is connected to ducts in the two bathrooms and in the kitchen and runs continuously during heating. A crank timer in both bathrooms can be turned to exhaust air temporarily when additional odor or moisture control is needed

- the Rosenburg supply fan is connected to an outside intake vent and runs continuously during cooling. A crank timer in both bathrooms can be turned on to boost the CFM of exhaust when additional odor or moisture control is needed

- the supply air during cooling is mixed with air in the plenum (to dilute the moisture from outside) and supplied to the air handler then distributed through the floor plenum. By taking these precautions, the potential for condensation within the floor plenum has been greatly reduced. The latent moisture load of the ventilation air is removed by the dehumidification capabilities of the heat pump cooling cycle.



Air Exhaust System

- 60 cfm of inside air is extracted from the house continuously during heating period via a fan, depressurizing the house enclosure
- air is extracted from bathrooms and kitchens eliminating the need for separate/additional exhaust fans
- fan operates by crank timers located in the bathrooms during cooling periods

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Conclusion

It is important to understand that the controlled ventilation system is not an energy saving feature. However, ventilation in a controlled manner in a tight enclosure is much more energy efficient than ventilation by random air leakage in a leaky building enclosure.

Random air leakage is driven by temperature differential induced stack pressures. Random air leakage during the heating season results in excessive air change due to large temperature differences between inside and outside. AS a result there is over-ventilation and the consequential energy penalty during the heating season. Conversely, random air leakage during the cool seasonal results in reduced air change due the absence of large temperature differences between inside and outside. As a result there is under-ventilation and the associated poor indoor air quality.

Do not consider controlled ventilation an option. Healthy homes cannot be built without controlled ventilation systems. Payback arguements do not apply where the ventilation system is concerned. Continuous ventilation is a basic requirement for all houses. Minimum health and safety requirements for shelter must be met. We believe that every house built in the United States will eventually have a controlled ventilation system. Already, most other industrialized countries in the Western Hemisphere have such a requirement. It is only a matter of time before building codes in the United States change to require controlled ventilation systems for all homes.

The controlled ventilation system also adds to the long term durability of the building. Excessive interior moisture levels can be avoided with the installation of a controlled ventilation system that provides for dilution with exterior air. Furthermore, installation of controlled ventilation systems in tight building enclosures can be used to control air pressure differences between the interior and the exterior on a seasonal basis. For durability reasons, a pressurized building enclosure is desirable during cooling periods. For similar reasons, a pressurized building enclosure is desirable during heating periods. A three pascal pressure limit, positive or negative, is required for air quality and comfort reasons.

Project Cost Summary

The total added cost of the controlled ventilation system installed was $650.00 (this includes a credit for not having to install two typical bathroom fans). The money saved by linking the downsizing of the heating/cooling system with the thermal upgrades of the building envelope ($500) was offset by the added cost of the controlled ventilation system ($650). The total added cost of the upgrade package was $150 per house. In other words, the construction cost savings of the energy conservation and resource conservation measures almost paid for the healthy house measures. The $150 added cost per house is paid back in only three months of utility bill savings (the upgrade package system saved $50/month in utility bills over comparable houses with typical insulation levels and HVAC packages).

Summary

It is possible and practical to build affordable, environmentally responsible housing without additional costs. It involves:

- careful selection of sites
- careful site layout
- careful floor plan layout
- careful design of the building enclosure
- careful selection and design of the building HVAC system
- careful selection of building materials

By applying the house system concepts in linking energy conservation, resource efficiency, and healthy houses technology, it is possible to use the cost savings accruing from energy conservation and an intelligent, non-wasteful use of resources to offset the added cost of healthy house technology. In this way, it is possible to build energy efficient, resource efficient, healthy houses without additional costs. This applies to the entire spectrum of the housing stock; high income, medium income and low income. This symbiosis of technology can be used to significantly houses alter the quality of life in affordable housing. Energy efficiency, resource efficiency, and healthy houses need not be the province of the rich or of custom builders, but instead can be fundamental traits that apply to all buildings.

About this Report

This report was first published in the 1994 EEBA Conference Proceedings: Resource Efficiency for the Nineties.

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