A Passive Solar Manufactured House
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Design Goals

- Efficiency: >90% solar heating
- Low cost
- Conventional interior with windows for views
- Simplicity - easy to build
- Autonomy - runs itself
- Robust - tolerant of errors
- Not a Status Symbol!
Solar Basement Design

- Basement provides solar collection and thermal mass.
- Basement is allowed to get hot, so glazing fraction can be high (22% of the floor area).
- Air circulates passively and actively.
- Basement window insulation is controlled.
- Heating system uses little electricity and provides storage space.
Ghost Mine Ranch
8250 feet elevation
(2800 feet higher than Boulder)
8600 Heating deg days,
(50% colder than Boulder)
Sunnier than Boulder
Numerical Model for Design

- Fortran 90 program written to model thermal performance of solar design.
- Model driven with 8 years of hourly weather data gathered by the CoAgMet station in Center, CO.
- Model includes solar gain through windows, 1D heat transfer in concrete, 2D transfer in berm and soil, conduction through house walls, air infiltration, heat transfer with basement fan, and backup furnace use.
- Predicted propane use 7 gal/yr for solar design and ~360 gal/yr for the control.
Model Benefits and Drawbacks

- Modeling aided our decision making:
  - window placement
  - thermal mass
  - amount of insulation
- Modeling provided estimates of control case without basement.
- Modeling wasn't as accurate as expected.
- Modeling lacked turbulent and radiative heat transfer.
Construction Errors

- Missing insulation around footers
- Extra infiltration due to gap between house and foundation
Program house_control.c uses picnet to control house.

Serial bus with 3 boards:
- A/D with temperature sensors
- Relay board
- Variable speed motor controller (unused)
**House sensors and controls**

- **Temperature Sensors**
  - basement window
  - basement air
  - basement north wall
  - house air
  - battery box

- **Control relays**
  - basement fan
  - basement insulation (garage door opener)
  - furnace
  - battery cooling pump and fan
  - heat recovery ventilator
  - power to internet hardware
Weather Station

- Davis Vantage Pro
- Data radioed to a data logger
- Download via serial port on house control computer
- Data uploaded to web and used to evaluate heating degree days
Efficiency Improvements

● House Window Insulation
  – Insulate windows at night in winter
  – 2 inch thick Styrofoam – R10

● Sine wave thermostat
  – Heat is transferred most efficiently when the basement is warmest
  – Solar system brings house to 75°F at 4PM, lets it fall to 65°F at 8AM

● White tarps in front of basement
Toepfer house comparison

- Our neighbor
- Same climate, size orientation + shape
- Heated with 6 cords wood per year
- 10 BTU/(sq ft HDD)
  - our house uses 0.2-0.7 BTU/(sq ft HDD)
Home Energy Saver Control

- Estimates energy use from:
  - construction, orientation and geometry
  - SHGC of windows, R-value of insulation
  - climate from weather station in Alamosa
- Correcting for actual HDD gives 930 gallons propane per year, compared to actual furnace use of 82 gallons in 2004-5 and 26 gallons in 2005-6.
- Our house is more than 90% solar heated.
Other Utilities

• water
  – ½ horsepower pump, UV water purifier
• sewer
  – engineered septic system, too little soil
• electricity
  – 100% solar powered, 1440W PV panels
• propane – 500 gallon buried tank
• internet
  – 5.8 GHz wireless, 13 miles from AP
• telephone – 3 Watt cell phone
Conclusions

- Basement cost ~ $30-40K more than a stem wall foundation.
- Basement saves roughly 850 gallons propane, currently $1700 per year.
  - Current yield ~5% but will increase with fuel prices
- Unique design may not have broad appeal.
Weekly Solar Flux on South Windows

- **Flux < 800 BTU/(ft²)**
- **800 < Flux < 1100**
- **1100 < Flux < 1400**
- **Flux > 1400**

![Graph showing heating intensity index vs. average outdoor temperature](image)
Embodied Energy

- Our house consumed energy in its building, especially the concrete:
  - 2MJ/kg \( \sim \) 1500 gallons propane
  - concrete energy offset in 1-2 years
- Solar panels offset their energy of manufacture in < 4 years.
  - result from Holland, much less sunny place.
- Location of the house costs \( \sim 370 \) gal gasoline/year, temporarily. For best efficiency, we should all live in cities.
Cost Summary

- Land (35 acres) - $36K
- Well and pump - 8K
- Foundation - 86K
  - about 70% basement
- Solar electricity - 21K
- Septic system - 20K
- House - 80K
- Automation - 5K

Total: $256K