Do-it-yourself Solar Thermal Heating Project-
Poquoson, VA
July 2011 – April 2012
Motivation for Project

1. Explore solar technology, benefit from tax incentives
2. Exercise my engineering skills
3. Be productive rather than watching TV
4. Improve comfort while watching TV, etc.
Air conditioning costs low compared to heating costs, so design system to reduce winter heating loads. Try a low-cost DIY radiant heat system rather than expensive (~$30K) photovoltaics.
System Block Diagram*

Radiant Heat System**

Thermal Reservoir

Solar Collector System

** Analyzed using Uponor Advanced Design Software
**Theory of Control**

1. **Start Radiant Heat Control Loop**
   - Enter desired room temp

2. **Start Collector Control Loop**
   - Enter desired room temp

3. **Rad Heat Pump = OFF**
   - YES: Rad Heat Pump = ON
   - NO: Collector Pump = ON

4. **T_{\text{room}} < \text{desired} ?**
   - YES: Collector Pump = ON
   - NO: Collector Pump = OFF

5. **T_{\text{tank}} > (T_{\text{room}} + 30^\circ F)?**
   - YES: Rad Heat Pump = ON
   - NO: Collector Pump = OFF

6. **Setback timer = ON?**
   - YES: Collector Pump = OFF
   - NO: Collector Pump = ON
3D CAD Model - Google SketchUp

Radiant Heat Circuits - family room, kitchen, laundry room, ½ bath

Radiant Heat Manifold

Reservoir, Circulators & Controllers

Collector Panels

Hot Water Heater (ref only)
Solar Collector Installation-

15° East of True South, 15° Elevation* from Horizontal

*vertical orientation maximizes collection in winter, minimizes in summer when unused
Reservoir Installation in Garage

- 250 gal of tap water
- Vented to atmosphere
Radiant Heat Distribution Manifold Installation in Coat Closet

Manifold Shutoff Valves, 2 places

Circuit Flow Adjustors

Pressure Pump for initial leak check only
Radiant Heat Installation:
610 sq ft: 2 Loops in Family Room, 1 in Kitchen, 1 in laundry room / bathroom

Joist Trak plates for ½” PEX tubing
Operator Interfaces

- Thermostat - Room
- Thermostat - Storage Tank
- Mixing Valve
- Pump Isolation Valves, 4 places
- Electrical Power Plug
- Collector Circulator Pump Controller
- Main Shutoff Switch
- Radiant Heat Circulator Shutoff Switch
- Setback Timer
- Fill / Drain Ports, 2 places
Project Management

- 9 month duration
- $6,565 material costs
- 288 man-hours,
  - Essentially by a single worker
  - Online research time was significant, but is not included
# Timeline of Project

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<td>Install Radiant Heat System</td>
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<td>- rmv underfloor insulation. Instl band joist insul, diffuser plates, pex pipe, manifold, 6&quot; underfloor insul</td>
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<td>Fab &amp; Install H2O Reservoir in garage</td>
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<td>Fab copper pipe grid assys for collectors</td>
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<td>Fab circulator panel assy, instl lines to Rad Heat manifold</td>
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<td>Fab collector assys</td>
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<td>Instl collectors, lines to reservoir</td>
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<td>1st water thru Collectors &amp; Rad Heat Sys</td>
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<td>Insulate collector lines. Instl lid on reservoir</td>
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Cost of Materials = $6,565

- Floor Insulation (incl labor), $937.48
- Tubing/ Joist Track Instl, $1,862.50
- Solar Collectors Assys, qty=3, $1,230.35
- Solar Collector Instl Hdwr, $218.83
- Reservoir, 250 gal, $513.22
- Circulator Instl Rad Heat Sys, $647.83
- Circulator Sys Collectors, $865.12
- Consumables, $289.84
Manhours

- 4 hrs / day worked, over 73 work days, by a single workman
- Band joist insul = 12.0 hrs for 95.5 linear ft = 8 linear ft / hr
- Rad heat instl = 73.9 hrs for 610 sq ft = 8.3 sq ft / hr
- Instl Manifold Feed Lines = 13.0 hrs
- Fab collector assemblies = 59.2 hrs = 19.7 hrs / assy
- Installation collector assemblies = 35.8 hrs = 11.9 hrs / instl
- Fab Reservoir = 20.7 hrs
- Fab Circulator Pallet = 42.0 hrs
- Collector Plumbing = 19.1 hrs

Total labor = 288 man-hrs
Performance of System:

• Predicted performance of Collectors and Radiant Heat System
• Data collection
• Analysis
  – Collection efficiency: overall, seasonal
  – Heating of house
  – Cost recovery
  – Reliability and Maintainability
Solar Obscuration Measurements

June 2011, 5’ above ridgeline of garage roof, x = 4’ out from 2nd story wall

Ridgeline = 166°

Trees on Property Line

Our Trees

Neighbor’s Tree
Predicted Energy Gathering
from comparable commercial collector

Norfolk Intl Airport, Viessman Vitosol 200F Power Output vs. Season
Moving Average of Previous 10 days,
T in=113F, T out=122F, Collector Az=-15 deg, Collector Elev=75deg,
1991-2005 Average = 442 BTU/sq ft/day

For three 4’x8’ collectors = 42,432 BTU/day

Predicted Heating Performance

• Calculated using free Advanced Design Suite software from Uponor
  – 68°F room temp, 24°F outdoor temp, 23 mph wind
  – 630 sq ft, average construction, Tin-Tout≤10°
  – 7,540 BTU/hr required = 1.8 gal/min @ 109°F

• Given predicted collector performance of 42,432 BTU/day, we’ll get 5.6 hrs of 68°F room temp each day.

• Existing heat pump runs in parallel.
  – Solar heat setpoint 2° above heat pump to draw from solar first
  – Degree of interaction unknown
Data Acquisition System

- Solely for initial testing, the removed Arduino based data logger
  - Real Time Clock for time stamping
  - SD Card Reader module for data storage
  - Cost approximately $60
- Dataset includes
  - Temp of room
  - Temp of H2O in Reservoir
  - Outdoor Temp
  - Temp in Garage
  - Insolation on Collectors
  - Radiant Heat Status (ON/OFF)
  - Time of day
Design Flaw = Freeze Up

- 23 Jan 2013 Overnight temp = 18 deg F
- Eastern & western collectors froze & split pipes. No leak in center collector.
- Pumped tank dry

Burst, 3 places

Flawed Design

Corrected Design 7-28-2013

Trap precludes breaking siphon, therefore NO DRAIN BACK!

- 23 Jan 2013 Overnight temp = 18 deg F
- Eastern & western collectors froze & split pipes. No leak in center collector.
- Pumped tank dry
Measured Collector Performance

- No heat draw from Reservoir (Rad ht OFF)
- Measure on cloudless days, no leaves on trees
- Heat gain = (Temp rise of tank) x (vol tank) x (density water) x (heat capacity of water)

12 March 2012:
Heat Gain = (100° - 74°) x (250 gal) x (62 lb/cu ft) x (1 BTU/lb/°F)
= 48,360 BTUs / day = **504 BTU / sq ft / day**

9 Nov 2012: 510 BTU / sq ft / day

vs. predicted avg of 450 BTU / sq ft / day. **Pretty Good!**
Measured Heating Performance

- Works well in spring and fall - no heat pump at all!
- Unclear about winter. Interaction w/ heat pump unclear, still figuring out ramp-up / down times
- Added set-back timer to heat rooms only in afternoon & evening
- With reservoir temp around 120°F, looses ~6° / night with unheated garage @ 50°
Was Project Successful?

1. *Explore solar technology, benefit from tax incentives*
   - Learned much about solar technology, only got minimal tax break for insulating floor

2. *Exercise my engineering skills*
   - YES! Design / build / test of plumbing, electrical, carpentry, controls, data logging

3. *Be productive rather than watching TV*
   - Yes. Watched little TV during the project

4. *Improve comfort while watching TV, etc.*
   - Yes. Den / kitchen was 60-62°F in winter, now 66-68°F
## Items in Block Diagram

<table>
<thead>
<tr>
<th>Item #</th>
<th>Description</th>
<th>Make</th>
<th>Model</th>
<th>Cost</th>
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<td>12</td>
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