Field Tests of Cool Walls in Cooling and Mixed Climates

André Desjarlais

Progress Report on Joint Research Project

Textured Coatings of America and the Oak Ridge National Laboratory

28 October 2005
Quiz

With **Comfort and Energy Efficiency** in mind, which car do you select to drive in the Panama City during the summer?
Potential Answers

- The black car (!)
- The white car
- Pick the black car and move to Denmark
- Who cares about energy efficiency or comfort?
Proof of Concept
Solar Energy Spectrum

Spectrum of Solar Radiance
Critical Properties

Reflectance \( (\rho_{\text{solar}}) \)  
Emittance \( (\varepsilon_{\text{IR}}) \)
$\rho_{\text{solar}}$ and $\varepsilon_{\text{IR}}$ are Both Very Important

Net Heat Flux into Building

Total Solar Irradiation

Convection

Net Infrared Radiation

$I_t$

$\rho_{\text{solar}} I_t$

Reflected

$h_{\text{air}}(t_{\text{air}} - t_s)$

$\varepsilon_{\text{IR}} \Delta R$

with $\Delta R = \sigma (T_s^4 - T_{\text{surr}}^4)$

$(\alpha_{\text{solar}} I_t$ Absorbed)

Net Heat Flux into Building
## Atlanta’s Changing Environment

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>[Image of 1972 environment]</td>
</tr>
<tr>
<td>1978</td>
<td>[Image of 1978 environment]</td>
</tr>
<tr>
<td>1993</td>
<td>[Image of 1993 environment]</td>
</tr>
</tbody>
</table>
Working with Industry Partners

- Team with metal roof, single ply membrane, and roof coating associations and their members and Textured Coatings
- Federally co-funded
Camouflage Invisible to Night Vision

Conventional Film

Near Infrared Film

Wavelength

400nm 500nm 600nm 700nm

0.01nm 0.1nm 1nm 10nm 100nm

Gamma Rays X-Rays Ultraviolet Visible Infrared Microwave Radio

Shorter Wavelength

Longer Wavelength

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY
Conventional vs. Infrared Pigments

![Graph showing reflectance (%) vs. Wavelength (nm) for UV, Visible, Infrared, Infrared-Reflecting, and Conventional pigments.](image-url)
Solar Energy Spectrum

Spectrum of Solar Radiance
Overview: Scope of Work

- Compare thermal performance of walls with cool (high infrared reflectance) and standard colors
- Use Textured Coatings of America’s SuperCote Platinum and SuperCote products
Overview: Scope of Work

- Phoenix site: Stucco-coated with various constructions facing east, south, southeast and southwest already covered with Mountain Gray color. Install instrumentation and recoat test areas.

- Jacksonville site: Wood siding facing south already covered with Underseas color. Install instrumentation and recoat test areas.

- Oak Ridge campus site: Bare stucco-coated test area facing south. Add instrumentation; prime and coat test areas.
Phoenix Site

- Single-story wings with central vaulted ceiling area for family room + dining room/kitchen
Phoenix Site

- Southeast and southwest exposures on walls of office in west wing. Outside temperature sensors attached to 10 3/4 in. thick walls
Phoenix Site

- Add gypsum panels for instruments to sense inside temperatures and heat flow through walls
Phoenix Site

- South and east exposures on walls of exercise room. South 15 in. thick; east 6¼ in. thick
Phoenix Site

- Data logger and modem in exercise room. Wires from west wing in shallow trench through yard
Phoenix Site

- Data logger transmits data through modem to computer at Oak Ridge over dedicated line
Phoenix Site

- Data obtained 5/2/04 through 11/30/04. Remove instrumentation on 12/2/04.

- Check consistency of data with program that estimates wall properties from measured temperatures and heat fluxes. R-values vary as expected.

- Different directions of exposure and varying thickness make it tough to interpret data.

- Limited height of walls and decorative overhang cause shadowing problems.
Phoenix Site: IR East vs IR Southwest

- IR East Outside
- IR East Inside
- IR Southwest Outside
- IR Southwest Inside

Weather data for 25th July 2004 (Eastern Time)

- Temperature (°F)
- Heat Flux, Solar/100 [Btu/(h·ft²)]

- Southwest heat fluxes (in office) sensitive to A/C fluctuations
- Peak daytime temperatures are consistent with exposure
Phoenix Site: Non Southeast vs IR South

- Southeast heat fluxes (in office) again show sensitivity to A/C fluctuations
- Peak temperature of south exposure shows shadowing effects

Heat Flux, Solar/100 [Btu/(h·ft²)]
Jacksonville Site

- Two-story house on Ponte Vedra beach
Jacksonville Site

- South-facing test exposures outside family room above steps from deck that faces ocean
Jacksonville Site

- Gypsum panels on inside walls painted to match existing decor
Jacksonville Site

- Data logger and modem tucked into corner behind TV. Used house phone line for monthly download. Owner plugged in phone line for call
Jacksonville Site

- Data obtained 5/5/04 through 12/3/04 with recoating on 7/9/04. Remove instrumentation on 12/8/04.

- Behaviors of solar flux incident on wall and outside surface temperatures show more cloudiness and rain than in Phoenix. Saw effects of Hurricanes Frances and Jeanne.

- Exposures not at same level (followed slope of steps) so some height effects both outside and inside.

- Railing for steps and enclosure for fireplace flue cause shadowing.
Jacksonville Site: Non Lower vs IR Upper

- Non Outside
- Non Inside
- IR Outside
- IR Inside

Heat Flux, Solar/100 [Btu/(h·ft²)]

- Outside wall temperatures equal at night
- Small peak temperature differences: coatings over existing coating

Heat Flux, Solar/100 [Btu/(h·ft²)]
ORNL Site

- Stucco test section on south wall of Envelope Systems Research Apparatus (ESRA)
ORNL Site

- Underseas Supercote Platinum (IR) on right stud space and upper half of middle; Supercote (Non) on rest except for strip of uncoated primer at bottom
ORNL Site

- Add gypsum panels on inside like at Phoenix and Jacksonville sites
ORNL Site

- Have ESRA data acquisition system in place and complete weather station next door
ORNL Site

- Computer dedicated to ESRA data acquisition records detailed thermal performance
ORNL Site

- Data starting 7/30/04 with coating on 8/3/04. Data acquisition through August 2005
- Check consistency of data with program to estimate wall properties from temperature and heat flux measurements. Data very consistent from month to month
- Behavior of solar radiation control on vertical walls more complicated than low-slope roofs. Difficult to generalize simply
Heat fluxes delayed four hours relative to outside temp

- Peak temps consistent with coatings over primer
- Non and IR behave identically at night
ORNL Site: Non vs IR -- Summer Day

- Air temp warmer but wall solar lower vs 4/16/05
- Behavior of Non and IR again same at night
- Peak temps again consistent with coatings over primer
Model for Wall Behavior

- Seek a model that can be generalized to give results for whole buildings
- Have done extensive validation of a model in DOE 2.2 for a 1100 ft² ranch house

Conventional Wood-Framed Construction

- Heat/cool with heat pump: 68°F winter; 76°F summer; size heat pump for climate
- Occupy with 3 people + Building America energy use profiles
Model for Wall Behavior

- To validate model, generate climatic data from ORNL weather station records for year of test
- Use properties of wall materials along with construction details for test section

- Fiberglass batt (R-11)
- Gypsum wallboard
- Measured heat flux
- Extra gypsum layer (only for validation)
- Texcote coatings with different solar reflectance
- Measured temperatures
- Stucco (1 in.)
- Non-vented air space
- Oriented strand board
Solar Reflectance of Coatings

- **Samples over primer:** Mountain Gray (Phoenix) and Underseas (Jacksonville and ORNL) 7/2/04
  - Mountain Gray Supercote Platinum: 0.44
  - Mountain Gray Supercote: 0.30
  - Underseas Supercote Platinum: 0.51
  - Underseas Supercote: 0.25

- **Jacksonville on wood siding and existing coating** 12/8/04
  - Underseas Supercote Platinum: 0.40
  - Underseas Supercote: 0.24

- **ORNL on Stucco** 8/4/04 9/27/04 5/18/05 8/3/05
  - Texcote Primer: 0.71 0.67 0.72 0.66
  - Underseas Supercote Pt: 0.49 0.50 0.49 0.49 0.50
  - Underseas Supercote: 0.24 0.24 0.24 0.24 0.24

Use averages
Features of DOE 2.2 of interest

- Can specify wall and solar reflectance of exterior surface and nearby ground
- Sun tracked hour by hour and can shade exterior surfaces by building and landscape
- Simulation of annual energy use by heating and cooling system includes response to thermostat schedules and to thermal mass in envelope
Model of South Wall vs Measurement: Temperatures at Outside – Spring Day

Measure (solar reflectance):
- IR surface (0.495)
- Non surface (0.238)
- Air

DOE 2.2 with ground reflectance =
- Surface measurements and DOE 2.2 predictions equal air temperature at night
- DOE 2.2 peak predictions above peak measurements
- Ground reflectance of 8% (dark soil, asphalt) better than 24% (dry grass) for spring day

Measure (solar reflectance): DOE 2.2 with ground reflectance =
- Surface measurements and DOE 2.2 predictions equal air temperature at night
- DOE 2.2 peak predictions above peak measurements
- Ground reflectance of 8% (dark soil, asphalt) better than 24% (dry grass) for spring day
Model of South Wall vs Measurement: Temperatures at Outside – Summer Day

Measure (solar reflectance):
- IR surface (0.495)
- Non surface (0.238)
- Air

DOE 2.2 with ground reflectance =
- 0.24
- 0.08

- DOE 2.2 peak behavior vs measurements not as regular as for 4/16/05
- Ground reflectance of 24% (dry grass) closer than 8% (dark soil) for this summer day.
Model Generalizations

- Building America Performance Analysis Resources at http://www.eere.energy.gov/buildings/building_america/pa_resources.html gives energy use profiles for three occupants (3 BR home). Choose to heat and cool with air-to-air heat pump (76°F cooling; 68°F heating; no setup or setback)

- Choose seven different climates to show response of typical house to cooling and mixed climates of interest

Cities arranged by decreasing cooling degree days
Model Generalizations

- Ranch house with non-IR reflecting coating on walls shows variation in heating and cooling energy use that is consistent with climate variation.

Heating + Cooling is 26% (Sacramento) to 44% (Richmond) of Total Electricity Use.

Rest of use is 4250 for appliances, 1330 for lights and 2200 (Miami) to 3230 (Richmond) for domestic hot water (varying T{water supply}).

Annual Electricity Use (kWh):
- Cooling
- Heating
- All Uses
Model Generalizations

- Alternate wall configuration of interest for cooling climates. Keep attic and floor insulation levels for consistency.

- Heating + Cooling is 29% (Sacramento) to 47% (Richmond) of Total Electricity Use.

- Concrete block walls cause more total energy use in all climates: +270 (Miami) to +850 (Richmond).
Model Generalizations

- IR reflective coating on conventional walls saves cooling energy. Savings are 4% to 9% compared to non-IR reflecting walls.

- Absolute savings vary from +240 (Phoenix) to +110 (Richmond).
Model Generalizations

- IR reflective coating on CMU walls shows larger savings of cooling energy. Savings are 6% to 13% compared to cooling energy with non-IR reflecting walls.

- Absolute savings vary from +360 (Phoenix) to +160 (Richmond).
Project Summary

- Demo sites in Phoenix and Jacksonville depict energy savings
- Full year of ORNL data validated DOE 2.2 model
- Complexity of real wall applications (different orientations, shading and construction) makes generalization very difficult
- DOE 2.2 whole building annual energy estimates for ranch house show that IR reflecting pigments save 4% to 13% of cooling energy
Project Summary

- Cooling a 1100 ft² ranch house in various climates
Field Tests of Cool Walls in Cooling and Mixed Climates

Questions or comments?