ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Stephen Wiel, Project Director
Energy Analysis Department
Environmental Energy Technologies Division

MS 90R4000
1 Cyclotron Road
Berkeley, CA 94720-8136

Tel. 510-486-5396
Fax: 510-486-6996
e-mail: Swiel@lbl.gov

December 14, 2004

To: Chris Scruton (CEC)
From: Steve Wiel
Subject: **Cool Roof Colored Materials**: Monthly Progress Report for November 2004
CC: Hashem Akbari, Paul Berdahl, Andre Desjarlais, Bill Miller, Ronnen Levinson

A summary of the status of Tasks and Deliverables as of November 30, 2004 is presented in Attachment 1. (Note the changes in the deliverables dates highlighted in yellow.)

HIGHLIGHTS

- We installed thermal monitoring instruments and connecting wiring for two residential homes in Redding, CA.
- The schedules of eight deliverables in Tasks 2.4, 2.5 and 2.6 were revised, leading to a one-year, no-cost extension of the final report to October 1, 2006.

Tasks

1.1 Attend Kick-Off Meeting
This Task is completed.

1.2 Describe Synergistic Projects
This Task is completed.

2.1 Establish the Project Advisory Committee (PAC)
This Task is completed.

2.2 Software Standardization
(No activity.)

2.3 PAC Meetings
(No activity.)

2.4 Development of Cool Colored Coatings

2.4.1 Identify and Characterize Pigments with High Solar Reflectance
Task Completed. Our pair of pigment-characterization papers, "Solar Spectral Optical Properties of Pigments, Part I: Model for Deriving Scattering and Absorption Coefficients from Transmittance and Reflectance Measurements" and "Solar Spectral Optical Properties of Pigments, Part II: Survey of Common Colorants" were accepted

without revision for publication in *Solar Energy Materials & Solar Cells*. We submitted finalized versions for publication.

2.4.2 Develop a Computer Program for Optimal Design of Cool Coatings
We continue to improve the mixture model on which our coating formulation software is based, and to develop the optimization algorithm.

2.4.3 Develop a Database of Cool-Colored Pigments
We are preparing an HTML version of our pigment database that will augment measured and computed solar spectral radiative properties with images of pigmented coatings, performance data from manufacturers, and technical commentary derived from our pigment papers.

2.5 Development of Prototype Cool-Colored Roofing Materials

2.5.1 Review of Roofing Materials Manufacturing Methods
Task Completed. The revised paper was distributed to the Industry Partners at the September PAC meeting. We have received reviewers' comments for the report. We will update the report and send it for publication in December 2004.

2.5.2 Design Innovative Methods for Application of Cool Coatings to Roofing Materials
We continued working with manufactures in developing cool shingle prototypes.

2.5.3 Accelerated Weathering Testing
An outline of the Accelerated Weathering Testing Report due in May 2005 is being formulated, along with a brief bibliography. The subject is color stability and material integrity after accelerated weathering tests. This information will be sent to our industrial partners in December with a request for further references and supplementary information, to fill in the gaps in the information currently on hand.

2.6 Field-Testing and Product Useful Life Testing
A Memorandum of Understanding was reviewed and approved by Ohoa and Shehan Inc. and ORNL for the proposed work demonstrating asphalt shingle roofing (Appendix A). Instruments and wiring were placed in two homes. Work continues to formulate and validate AtticSim for tile roofs.

2.6.1 Building Energy-Use Measurements at California Demonstration Sites
ORNL personnel worked with Jerry Wagar of Ochoa and Shehan Inc. to install thermal monitoring instruments and connecting wiring for two residential homes in Redding, CA.

Wagar placed the homes on two different street cul-de-sacs so that both homes would have the same roof orientation (i.e., each home's roof ridge runs north-south, see Fig. 1). The ranch style homes each have about 2400 square feet of floor space, and have two split system air-conditioning units for comfort cooling. Wagar stated that summer air temperatures often exceed 100°F, while winter temperatures can drop below 32°F. Therefore thermometry measurements will include both the surface and underside temperatures of the shingles exposed on the east- and west-facing roofs as well as the heat transfer crossing the direct nailed shingles and the heat transfer crossing the ceiling of each home. Wiring for whole house and air-conditioning power measurements were also provided for assessing benefits of CRCMs on the home's utility charges.

Figure 1. The pair of homes in Redding CA for demonstrating asphalt shingles with and without CRCMs.

Miller, Wagar and Don Zadrozna, sales representative for Elk Shingle, met Monday Nov 29 to review the scope of work and the responsibilities for ORNL, Ochoa and Shehan Inc. and Elk for monitoring the thermal performance of the homes over a two-year period. Wagar agreed to fully support the project and was very helpful with setup of the instruments, phone lines, instrument wiring and placement of the data logger. Zadrozna agreed to periodically visit the demonstration site and remove a couple shingles from each home for Elk to conduct chemical and mechanical analysis. However, further negotiations are required to obtain Elk's concurrence for conducting the analysis of field exposed shingles with and without CRCMs.

Miller will request Elk conduct Corbett fractionation and gel chromatography (or equivalent) procedures to judge the chemical and flexural properties of the shingles with CRCMs as compared to Elk's standard production shingle. Terrenzio et al. (2002) showed that heating of asphalt shingles promotes the diffusion and vaporization of oils from the asphalt with the subsequent migration of oxygen into the asphalt. Terrenzio noted that as aging progresses, the stiffness of the asphalt increases. The Corbett fractionation and gel chromatography testing of the exposed shingles will hopefully show the benefit of the shingle with CRCMs because it will incur less heat aging (especially in Redding, CA where summer air temperatures can exceed 100°F) as compared to the standard production shingle being exposed on the control house.

Trrenzio L.A., Harrison J.W., Nester D.A.and Shiao, M.L. 2002. "Natural vs Artificial Aging: Use of Diffusion Theory to Model Asphalt and Fiberglass-Reinforced Shingle Performance." Proceedings of the 4th International Symposium on Roofing Technology, v 66.

2.6.2 Materials Testing at Weathering Farms in California
(No activity)

2.6.3 Steep-slope Assembly Testing at ORNL

Our validation work reported last month showed that AtticSim did an excellent job of predicting the ceiling heat flux penetrating the attic assembly with a standard production direct nailed shingle roof. However work continues to adapt the code for more accurately predicting the heat transfer in tile roofs that have thermal mass and also a venting occurring between the roof deck and the underside of the tile. The challenge is to accurately predict the airflow within the inclined air cavity. Once the flow rate is known, the portions of heat penetrating the roof deck and that convected away from the deck are obtained from energy balances.

Temperatures of the OSB, on the attic side, and of the bulk air within the inclined air cavity were measured in the clay tile (SR54E90) roof system to better understand the physics of the problem and help formulate a procedure for predicting the airflow and in turn the heat transfer. An energy balance for the inclined air cavity shows that the energy supplied to the air from the roof less the energy absorbed by the deck equate to the temperature gradient of the bulk air as it traverses from soffit to ridge. This energy balance takes the form:

$$\left(\frac{dT_B}{dX}\right)_{air} = \frac{W}{(\dot{m}C_P)_{air}}\left(q''_{Roof} - q''_{Deck}\right)$$

and assumes that axial conduction in the air is negligible. Integrating the energy balance over the length of the roof yields the heat convected away by buoyancy and wind forces within the inclined air channel; it being equal to:

$$\dot{Q}_{Vent} = \dot{m}C_P\left(T_{Ex\,Ridge} - T_{in\,Soffitt}\right) = \frac{W \cdot L}{(\dot{m}C_P)_{air}}\left(q''_{Roof} - q''_{Deck}\right)$$

The bulk air and OSB temperature data for the clay tile are plotted in Figure 2 for measurements collected at 8 am and also at solar noon around 2 pm. The air temperature

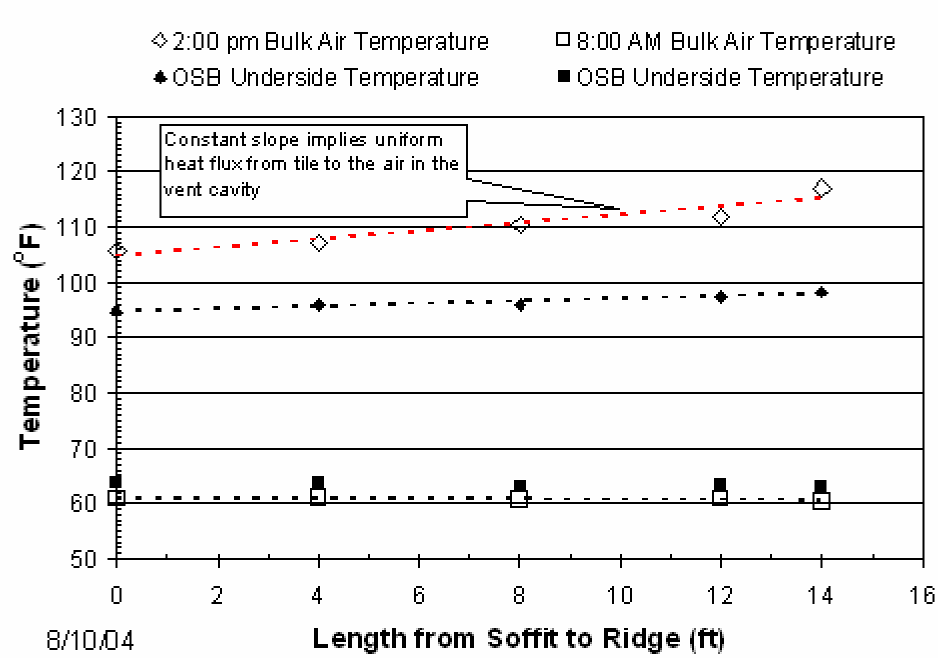

Figure 2. Bulk air and deck temperature measured in the inclined air channel of the clay tile roof.

data measured at solar noon (2 pm) is very interesting because it shows that the gradient of the bulk air temperature is linear with length along the sloped roof. In other words, the slope is constant and therefore the net heat flux across the air channel is constant. This in turn infers that the airflow did not leak out from between the overlapped clay tiles.

Anderson and Bejan (1980) studied the situation of an exterior building wall separating two fluid chambers of air at different temperatures. They observed that the temperature of the wall "floats" such that it increased in temperature with increasing altitude and the heat flux through the wall was essentially uniform. The OSB deck temperatures in Figure 2 behave in similar fashion. The inference that the air moving up the inclined channel is conserved and does not leak out between the overlapped tiles even though tile roofs are specifically designed to be porous was also observed by Geert Houvenaghel of the Katholieke University, Leuven. Houvenaghel measured the airflow in the inclined cavity using a sulfur-hexafluoride tracer gas. His data confirms the observations for tile roofs observed by ORNL provided the strength of wind sweeping the tile is relatively low. The uniform and constant roof heat flux concept can therefore be used in an iterative manner to predict the bulk air temperature, the airflow and the heat flow occurring in the inclined air gap.

Derivation of the governing equations are not provided but are stated to show the approach to be tried for modeling tile roof systems. The inclined air channel has length L and hydraulic diameter D. Equating the flow resistances of friction and hydraulic losses to the pressure driving forces of buoyancy and wind a pressure balance is formed:

$$\underbrace{\Delta P_h}_{\text{hydraulic losses}} + \underbrace{\Delta P_f}_{\text{friction}} = \underbrace{\Delta P_B}_{\text{buoyancy}} + \underbrace{\Delta P_W}_{\text{Wind}}$$

Using energy, continuity and force balances for fully developed incompressible flow and invoking the Boussinesq approximation, yields expressions for each of the above terms, and after rearranging yields the following expression:

$$A\left(L^+\right)^3 + B\left(L^+\right)^2 - 0.5\left[\left(f_{app}\,Re_D\right)L^+ + \sum K_h\right] = 0$$

where

$$A = 2S\,SIN(\theta)\frac{Ga_D}{Pr}$$

$$B = \frac{\Delta P_{Wind}\,D_h^4}{\rho\,\nu^2\,L^2}$$

$$L^+ = \frac{L}{D_h\,(Re_D)}$$

$$Ga_D = \left(\frac{g\beta}{\nu^2}\right)\frac{\dot{q}_{vent}D_h^5}{L\cdot k}$$

$$Re_D = \frac{UD_h}{\nu}$$

The formulation can be solved for the mass flow of air given a reasonable estimate for $\dot{q}_{vent}$ using a Newton-Raphson procedure to iterate on the mass flow rate of air. The heat transfer coefficients for natural and mixed convection are calculated and reevaluated until the approach converges on both $\dot{q}_{vent}$ and $\dot{m}_{air}$. Bejan(1984) provides a useful table of heat transfer correlations for the case where the heat transfer leaks from the attic and

out through the roof surface. Brinkwork (2000) has conducted an extensive validation for the case where the heat transfers from the tile surface, through the inclined air channel and on into the attic.
The algorithm and correlations shall be implemented in the computer simulation code AtticSim, and efforts will continue to formulate and validate AtticSim for concrete tile roofs.

Bejan A. 1984. Convection Heat Transfer. John Wiley & Sons, Inc., New York.

Brinkworth, B.J. 2000. "A Procedure for the Routine Calculation of Laminar Free and Mixed Convection in Inclined Ducts." International Journal of Heat and Fluid Flow, v 21, p. 456-462.

Houvenaghel, G., Katholieke University, Leuven. Houvenaghel, personnel communication.

2.6.4 Product Useful Life Testing

A report on weathering mechanisms in various roofing types is due in May 2005. An outline and bibliography are in preparation. This information will be sent to our industrial partners with a request for further references and supplementary information, to fill in the gaps in the information currently on hand.

2.7 Technology transfer and market plan

2.7.1 Technology Transfer

(No activity.)

2.7.2 Market Plan

(No activity.)

2.7.3 Title 24 Code Revisions

Akbari continues working with PG&E and Energy Commission to develop a plan for code change proposal for sloped-roof residential buildings.

Management Issues

- Scruton and Akbari fine-tuned the schedules of project tasks and deliverables. The schedules of eight deliverables in Tasks 2.4, 2.5 and 2.6 were revised, leading to a one-year, no-cost extension of the final report to October 1, 2006.

Attachment 1

Project Tasks and Schedules (*Approved on May 16, 2002; Revised schedules approved November 2004*)

Task	Task Title and Deliverables	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 11/30/2004
1	**Preliminary Activities**					
1.1	Attend Kick Off Meeting *Deliverables:* • Written documentation of meeting agreements and all pertinent information (**Completed**) • Initial schedule for the Project Advisory Committee meetings (**Completed**) • Initial schedule for the Critical Project Reviews (**Completed**)	5/16/02	5/16/02	6/1/02	6/10/02	100%
1.2	Describe Synergistic Projects *Deliverables:* • A list of relevant on-going projects at LBNL and ORNL (**Completed**)	5/1/02	2/1/02	5/1/02	5/1/02	100%
1.3	Identify Required Permits	N/A		N/A		
1.4	Obtain Required Permits	N/A		N/A		
1.5	Prepare Production Readiness Plan	N/A		N/A		
2	**Technical Tasks**					
2.1	Establish the project advisory committee *Deliverables:* • Proposed Initial PAC Organization Membership List (**Completed**) • Final Initial PAC Organization Membership List • PAC Meeting Schedule (**Completed)** • Letters of Acceptance	6/1/02	5/17/02	9/1/02		100%
2.2	Software standardization *Deliverables:* • When applicable, all reports will include additional file formats that will be necessary to transfer deliverables to the CEC • When applicable, all reports will include lists of the computer platforms, operating systems and software required to review upcoming software deliverables	N/A		N/A		

Project Tasks and Schedules (contd.)

Task	Task Title and Deliverables	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 11/30/2004
2.3	PAC meetings *Deliverables:* • Draft PAC meeting agenda(s) with back-up materials for agenda items • Final PAC meeting agenda(s) with back-up materials for agenda items • Schedule of Critical Project Reviews Draft PAC Meeting Summaries • Final PAC Meeting Summaries	9/1/02	6/1/02	6/1/05		83% (5/6)
2.4	Development of cool colored coatings					
2.4.1	Identify and Characterize Pigments with High Solar Reflectance *Deliverables:* • Pigment Characterization Data Report	6/1/02	6/1/02	12/1/04 → 12/31/04		~ 99%
2.4.2	Develop a Computer Program for Optimal Design of Cool Coatings *Deliverables:* • Computer Program	11/1/03	11/1/03	12/1/04 → 5/1/05		~ 85%
2.4.3	Develop a Database of Cool-Colored Pigments *Deliverables:* • Electronic-format Pigment Database	6/1/03	7/1/03	6/1/05 → 12/31/04		~ 90%
2.5	Development of prototype cool-colored roofing materials					
2.5.1	Review of Roofing Materials Manufacturing Methods *Deliverables:* • Methods of Fabrication and Coloring Report	6/1/02	6/1/02	6/1/03		~ 99%
2.5.2	Design Innovative Methods for Application of Cool Coatings to Roofing Materials *Deliverables:* • Summary Coating Report • Prototype Performance Report	6/1/02	6/1/02	12/1/04 → 5/1/05		~ 90%
2.5.3	Accelerated Weathering Testing *Deliverables:* • Accelerated Weathering Testing Report	11/1/02	10/1/02	6/1/05 → 10/1/05		~ 25%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 11/30/2004
2.6	Field-testing and product useful life testing					
2.6.1	Building Energy-Use Measurements at California Demonstration Sites *Deliverables:* • Demonstration Site Test Plan • Test Site Report	6/1/02	9/1/02	10/1/05 → 10/1/06		82%
2.6.2	Materials Testing at Weathering Farms in California *Deliverables:* • Weathering Studies Report	6/1/02	10/1/02	10/1/05 → 10/1/06		65%
2.6.3	Steep-slope Assembly Testing at ORNL *Deliverables:* • Whole-Building Energy Model Validation • Presentation at the Pacific Coast Builders Conference • Steep Slope Assembly Test Report	6/1/02	10/1/02	10/1/05		65%
2.6.4	Product Useful Life Testing *Deliverables:* • Solar Reflectance Test Report	5/1/04	5/1/04	6/1/05 → 10/1/05		20%
2.7	Technology transfer and market plan					
2.7.1	Technology Transfer *Deliverables:* • Publication of results in industry magazines and refereed journal articles • Participation in buildings products exhibition, such as the PCBC Brochure summarizing research results and characterizing the benefits of cool colored roofing materials	6/1/03	6/1/02	6/1/05		~ 75%
2.7.2	Market Plan *Deliverables:* • Market Plan(s)	5/1/05		6/1/05		
2.7.3	Title 24 Code Revisions *Deliverables:* • Document coordination with Cool Roofs Rating Council in monthly progress reports • Title 24 Database	6/1/02	5/16/02	6/1/05		~ 20%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 11/30/2004
VII	Critical Project Review(s) *Deliverables:* • Minutes of the CPR meeting					
XII (C)	Monthly Progress Reports *Deliverables:* • Monthly Progress Reports	6/1/02	6/1/02	6/1/05		75% (27/36)
XII (D)	Final Report *Deliverables:* • Final Report Outline • Final Report	3/1/05 → 3/31/05		10/1/05 → 10/1/06		
	Final Meeting *Deliverables:* • Minutes of the CPR meeting	10/15/05		10/31/05		

Appendix A

Draft Memorandum of Understanding

Demonstration of Standard Production Asphalt Shingles and Advanced Shingles having Cool Roof Color Materials on Homes in Redding, CA

This Memorandum of Understanding represents an agreement by Oak Ridge National Laboratory (ORNL), the Elk Group Inc. and Ochoa and Shehan Inc, a residential construction firm in Redding, CA to cooperate in the field testing and demonstration of cool roof colored materials (CRCM).

Whereas, the California Energy Commission (CEC) has contracted the Lawrence Berkeley National Laboratory (LBNL) and the Oak Ridge National Laboratory (ORNL) to develop cool roof colored materials (CRCM) that are visibly dark but can reflect light like a "white" roof in the infrared portion of the solar energy spectrum.

LBNL and ORNL are working with the tile, metal, cedar shake and asphalt-shingle roofing industries to accomplish the CEC goal of making CRCM a market reality for all residential roof products within the next five years.

Whereas, the CEC's objectives are 1) to offer consumers information that promotes the development and increased use of highly reflective CRCM and 2) to develop colored composition shingles with solar reflectance of at least 25% and tile and metal materials with reflectance of 50% or more.

Whereas, the Building Envelope Group of the ORNL intends, with support from the Elk Group Inc. and the cooperation of Ochoa and Shehan Construction to set up in November 2004 two residential demonstrations consisting of a pair of single-family detached homes that have composition shingle roofs with and without cool roof color materials.

Whereas, Elk is providing asphalt shingles at no cost for Ochoa and Shehan Construction to install on two homes in Redding CA in exchange for acquiring temperature, heat flow and power measurements for the two homes over the course of a two year field study.

ORNL personnel will instrument the two homes during construction slated for November 2004, and will monitor the homes over a two-year period ending October 2006.

Whereas, Table 1 lists all the instrument measurements currently proposed by ORNL and Elk

Therefore, the parties agree to undertake the activities described below or otherwise agreed in writing during the course of the demonstration project:

Demonstration Homes

1. Ochoa and Shehan Construction will make two demonstration houses available in 2004 for the field testing demonstrations described below.

Instrumentation for each Home

2. ORNL personnel shall make 2-ft by 2-ft sandwich test panels of the same material as used for the roof decks at the demonstration homes, probably oriented strand board (OSB). Each sandwich panel will be made of two sections equaling the same thickness as the rest of the deck. The two panels will sandwich thermocouples and a heat flux transducer for measuring thermal performance of the roofs. A spare thermocouple will be included for possibly measuring the surface temperature of the shingle roofs.

3. Ochoa and Shehan Construction will notify ORNL of the start date for constructing the roof decks, and ORNL shall ship sandwich test panels to Ochoa and Shehan Construction prior to the specified start date.

4. ORNL will contract Ochoa and Shehan Construction to install the sandwich test panels as part of the deck for the test roofs. The orientation of the homes makes it necessary to use two panels per house.
The roofing contractor will center and attach one panel to preferably a south-facing roof and center and attach the other to preferably the north-facing roof.

5. ORNL personnel under the supervision of Ochoa and Shehan Construction shall instrument the attic for measuring the attic air temperature and relative humidity and the temperatures around the ceiling insulation as well as the ceiling heat flux. A temperature and relative humidity probe will be mounted in the return duct to measure the return air temperature and relative humidity from the house (see Table 1 for a listing of measurements).

6. ORNL personnel under the supervision of Ochoa and Shehan Construction will install two Model WNA-1P-240-P Wattnode transducers for measuring the whole house power consumption and the power draw of the HVAC system. The meters shall be housed in weatherproof NEMA enclosures and placed on an exterior wall near the power panel for each home. An event counter (Campbell Scientific model ACL1) shall be installed in the condensing unit of the air-conditioner for measuring its cycling rate.

7. ORNL personnel shall install two pyranometers, one on the south facing roof and the other on the north facing roof of each house in an inconspicuous place near the roof ridge. The instruments have about a 3-in diameter and stand about 2-in off the roof. Instrument wires will be hidden by running them through the ridge or louvered vents into the attic and down inside an exterior wall to a data acquisition system (DAS) housed in a white plastic NEMA enclosure.

Data Acquisition System

8. ORNL personnel under the supervision of Ochoa and Shehan Construction shall install a data acquisition system an exterior wall of each house (near the power panel) and shall make all instrument connections to the DAS. Placement of the DAS in the attic is not encouraged because

problems do occur even with the best DAS and placement on an exterior wall near the power panel would cause the least hassle for the technician and the least intrusion for the homeowner.

We will use a Campbell Scientific Model CR23X-4M micro-logger with model AM25T multiplexer for expanded channel capability. The DAS shall be in a NEMA 4 weatherproof and lockable enclosure. The DAS shall have 4 megabytes of extended memory, a phone modem, modem surge protector and rechargeable battery. The battery requires a 115 Vac source and therefore ORNL requests the DAS be placed near the power panel for obtaining the necessary instrument power. ORNL shall provide an independent phone line for communicating with the DAS.

9. ORNL shall fully program the DAS and shall fully document the data acquisition code for use in later trouble shooting problems by ORNL or LBNL personnel.

10. ORNL with support from Ochoa and Shehan will direct the phone service to run independent phone lines for hook up to each DAS for transmitting data by modem. These lines will be completely independent of the homeowner’s phone system, and shall remain intact for the 2-year field demonstration.

11. ORNL shall weekly check the data string output by the DAS received over the modem, and shall take responsibility for damage to the DAS and instruments, and will themselves make appropriate repairs.

Air Tightness of Houses (optional-dependent upon permission of homeowner)
12. ORNL under the coordination of Ochoa and Shehan Construction and the homeowners shall measure the air tightness of the demonstration homes using a Minneapolis Blower Door test apparatus. A Duct Blaster™ apparatus will be used to check the tightness of the air duct system. Both outside air infiltration and duct leakage will affect air conditioning performance therefore we will attempt to document the tightness of the two homes. The air tightness of the house and ducting shall be checked after Ochoa and Shehan has completed construction but before the homeowner occupies the homes.

13. ONRL also requests the opportunity to conduct the air tightness testing at conclusion of the two-year study, and will coordinate the testing per the approval of the homeowner.

Onsite Reflectance Measures
14. ORNL, LBNL or Elk personnel will visit the site semiannually to measure the reflectance of the test roofs. The measures will require personnel to climb up a ladder to the roof and make the measurement, which will take only about 15 minutes.

Thermal Scans of Houses (optional-dependent upon permission of homeowner)
15. ORNL personnel request the opportunity to make thermal scans of the homes to judge the relative effectiveness of the roofing systems once the homes are built and occupied. As the roof systems age the thermal scans will help document the overall thermal performance of the roof as

compared to their starting performance. The scans are taken outside the home and will be conducted yearly.

Composition Shingle Retrieval (optional-dependent upon permission of homeowner)
16. ELK personnel request the opportunity to remove and replace one possibly as many as three shingles from the roof facing the back of each home on an annual basis. Elk will take the field exposed shingles and conduct some mechanical testing to confirm that the new shingles with CRCMs perform in a consistent manner with existing standard production shingles. Appropriate data shall be shared with ORNL for support of the CEC work contracted to ORNL and LBNL.

Visitation
17. The homeowners shall agree to allow visitation privileges to ORNL, LBNL or ELK personnel in case of maintenance, repair, routine checks of instruments or the DAS. However, all visits will be coordinated through Ochoa and Shehan Construction or the homeowner's permission to egress said property. Therefore personnel shall schedule visits amenable with the homeowner prior to the actual visit. Visits will be limited to field acquisition and or checks to trouble-shoot instruments and or the DAS.

18. At completion of the two-year study ORNL will remove the DAS, instruments and wires with exception of those embedded in the roof deck.

CONTACTS

ORNL Building Envelope Group	ELK Group, Inc.	Ochoa and Shehan Construction Company
Andre Desjarlais, Group Leader	**Louis T. Hahn** Technology Center Manager	**Jerry Wagar** Principal Owner
Signature:	Signature:	Signature:
Phone: 865-574-0022	Phone: 972-872-2293	Phone: 530-221-0527
FAX: 865-574-9354	FAX: 972-872-2399	FAX: 530-221-0544
E-mail: desjarlaisa@ornl.gov	E-mail: LouHahn@ElkCorp.com	Email: Ochoa@Shasta.com

Table 1. Instruments specified for measuring the building envelope thermal performance of each house having asphalt shingles.

Instrument	Description	Location	Attachment	Channel	
South Facing Roof					
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Spare for Roof Surface	Epoxy	8 T	
"	26 AWG Unshielded bead	Deck	Taped	7 T	
"	26 AWG Unshielded bead	In Deck	Embedded between OSBs	6 T	
Heat Flux Transducer	2-in by 2-in by 0.125-in thick	In Deck	Embedded between OSBs	2 Rd[+]	
Pyranometer Li-Cor	Solar Probe	Near ridge at roof gable	Mounting bracket	4	
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Deck underside	Taped	5 T	
North Facing Roof					
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Spare for Roof Surface	Loctite Epoxy	4 T	
"	26 AWG Unshielded bead	Deck	Taped	3 T	
"	26 AWG Unshielded bead	In Deck	Embedded between OSBs	2 T	
Heat Flux Transducer	2-in by 2-in by 1/8-in thick	In Deck	Embedded between OSBs	1 Rd[+]	
Pyranometer Li-Cor	Solar Probe	Near ridge at roof gable	Mounting bracket	5	
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Deck underside	Taped	1 T	
Attic interior					
Vaisala 50Y	DB & RH Probe	Attic air 4-ft above insulation	Run along support wire	6	
Thermocouple (Type T Cu/Con)	26 AWG Shielded bead	Top of insulation	Laid atop insulation	10 T	
	26 AWG Unshielded bead	Sheet rock surface facing attic	Taped	9 T	
Heat Flux Transducer	2-in by 2-in by 1/8-in thick	Sheet rock surface facing attic	Sandwiched between insulation and sheet rock	3 Rd[+]	
House exterior above ridge vent (Not Applicable)					
Vaisala 50Y	DB & RH Probe	Ambient air 3-ft above roof	Mounting bracket	NA	
Anemometer	Wind velocity	Ambient air 3-ft above roof	Mounting bracket	NA	
Wind Vane	Wind direction	Ambient air 3-ft above roof	Mounting bracket	NA	
House interior					
Vaisala 50Y	DB & RH Probe	Entering return grill	Duct mounted	7	
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Leaving evaporator coil	Run along support wire	11 T	
Wattnode transducer	Model WNA-1P-240-P	Total House Power	NEMA enclosure on exterior wall	8	_______
Wattnode transducer	Model WNA-1P-240-P	HVAC Power	NEMA enclosure on exterior wall	9	_______
ACL1 Event counter	OPTI-Line Monitor with DC power supplied by CR23X	HVAC cycling rate	Installed in outdoor condensing unit and wires run to DAS.	10	_______