A BUILDING MATERIALS RESEARCH AGENDA

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ABSTRACT

An ad hoc panel of individuals was organized to propose a research agenda, scope and objectives that the U.S. Department of Energy/Oak Ridge National Laboratory Building Materials Research Program should pursue. The panel recognized accomplishments and advances made over the past five years in selecting agenda projects. It composed an extensive list of candidate research projects and selected twenty-four as most significant. Each of the twenty-four projects was characterized by a two page description that detailed objectives, scope, problem significance, technical approach, and research products.

The panel also recommended that the Building Materials Research Program adopt an Advanced Program Scope that would expand the number of applied research projects. In addition, the panel suggested that a Cooperative Project Mode alternative be considered. A cooperative project involves a group of organizations that have common interest in a research issue. The group would pool its resources to accomplish a common objective and in directing the research.

INTRODUCTION

The primary purpose of buildings is to provide a more favorable environment than that provided by the natural surrounding climate. Buildings are expected to meet the following broad performance requirements: (1) sufficient strength to withstand all of the applied internal and external loads; (2) economy in first cost, operating cost, and maintenence cost; (3) satisfactory appearance in the context of its use and occupancy.

A wide variety of natural, processed, and manufactured materials and combinations of materials is used in the construction of major building components. Very few, if any, single materials meet all of the important performance requirements for the principal components of a building. Consequently, materials are typically combined by builders and designers in ways that meet the most important performance requirements. The marginal performance characteristics of one material are offset or compensated for by a strong performance characteristic of another material.

In combining materials for a building envelope the designer, builder, and/or manufacturer needs to have reliable and accurate information on the principal performance characteristics and the relevant marginal characteristics of all the materials that he proposes to use in a building. Likewise, the researcher who develops analytical models of prospective constructions needs to have accurate technical data on the performance characteristics of the various materials proposed for a building design.

It is generally accepted that the insulating materials used in a building envelope provide most of the thermal resistance of the envelope. A variety of factors can decrease the as built insulating effect: air infiltration, moisture condensation, rain leakage, shrinkage, cracking, settling, polymerization of plastics, aging, excessive temperature or humidity, thermal anomalies, membrane puncture,expansion and contraction, and workmanship. Control of these negative

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factors often depends on the performance of the noninsulating materials used in a building envelope design. Thus, in promoting the design and construction of durable energy-efficient buildings, it is necessary to have reliable published data on a range of performance characteristics for all of the materials likely to be combined in the building design.

Building materials are usually selected to satisfy the above general requirements. However, materials also have a significant impact on building user comfort and productivity. For example, it is understood by the designer that a large, unheated glass window can cause discomfort during high and low outside temperatures. The high radiant heat transfer between the space occupant and the glass causes discomfort to a person near the glass. The designer uses several strategies to control the heat transfer, some involve using other building materials in combination with the window glass. There are other examples, but a systematic study of the impact of building materials on comfort and productivity has not been undertaken. Significant research is underway to determine the in-situ performance of materials, and many comfort studies have been done. But the two have not been combined to relate discomfort with a failure or misuse of building materials.

SCOPE AND OBJECTIVE

The U.S. Department of Energy through the Oak Ridge National Laboratory (DOE/ORNL) wished to develop a research agenda and an advanced scope that could be used as a guide for the Building Materials Program over the next five years. DOE/ORNL wanted a panel to consist of a range of researchers and designers who are working with materials that affect the thermal envelope performance and who are involved with professional organizations concerned with building materials.

The panel was to develop a research agenda consistent with other DOE/ORNL planning documents and provide supporting detail to meet the requirements of the DOE management structure and budget process. In addition, the agenda could be used for developing cooperative programs with industry and academia. Although primarily a DOE/ORNL document, the panel was to keep in mind the impact of proposed research on manufacturers, associations, academic institutions, and other government agencies who are planning and conducting research on building materials.

The recommended projects should fit DOE's mandate of funding only those long-term, high-risk projects that are not part of the private sector's responsibility to develop products. The panel considered all building materials for new and retrofit construction of all building types. The scope included all aspects of building materials:

- all properties, in addition to thermal
- applications in design and construction
- field performance, short- and long-term
- characteristics, individual and interactive
- ideal materials for particular application
- adoption of materials used outside of the building industry.

The objective was to develop an organized list of building materials research projects that would result in data and design tools useful in the application of materials in energy-efficient buildings. The work was to take a step beyond listing titles and to write project descriptions for a subset of projects considered to be the most important. An equally important objective was to advance the DOE/ORNL Building Materials Research program scope. The program scope was to include applied research that would extend basic research work into results more directly related to the design.

A panel of individuals with expert knowledge of the many materials that are used in buildings was convened to write a diversified research agenda. The intent in organizing the panel was to have members that represent each generic building material and designers concerned with using and specifying materials. Specific categories for panel membership were wood and wood products, concrete and masonry, plastics, general building products, and building design.

Each of the ten panel member has extensive experience, ranging from 10 to 40 years, with building materials. Everyone has been involved with research, usually focused on a specific building material. Participation in the panel's work was as knowledgable individuals rather than as representatives of a particular company or association.

STRUCTURE OF RESEARCH AGENDA

There is an urgent need to translate basic research into design practice and for a significant increase in the examination of materials in combination under in-situ conditions. An investigation of the interactive, dynamic performance of materials in combination within an envelope system and within whole buildings is vital to understanding the limitations of present materials and the future potential of new materials and new combinations of materials.

Materials must serve multiple functions, including appearance. A ready example is insulation. It is selected for its thermal resistance or R-value. Insulation has an impact on the flow of air and moisture through the envelope as well. If the wall is made airtight to control the impact of moisture on thermal performance, there could be a problem with high interior humidity, i.e., indoor air quality.

It is clear that the selection and application of materials has many ramifications and that individual materials can be combined in many ways. The information necessary to satisfy the building design process might start with establishing the performance needed by material users. The needs can be converted into a set of material performance criteria and performance requirements. Solutions concerned with the total building design can then be generated. The final step is a performance test of the materials in-situ to determine if the criteria were met. Feedback during the final step leads to modification and improvement of the criteria.

The diagnostic procedures, tools, and instrumentation needed for measuring materials performance in relationship to user requirements is a beginning technology. As building design becomes more sophisticated, design and construction limits become tighter and tolerances narrower. The growing technology will impact all aspects of building design and particularly energy management.

Of particular concern to the panel was how to accommodate the architect in his application of combinations of materials. What restrictions in building design are caused by limited data and a limited understanding of the performance of materials in combination? If new information is uncovered through research and presented in a form that is useful to an architect, the architect will use it in creative new designs. At the same time, unless the architect articulates the material characteristics needed to fulfill his design concepts, the researcher cannot respond. Researchers and architects must find a forum to exchange ideas and needs.

A group of architects who have shown a concern for energy-conscious design gave a symposium in 1979 at Cornell University. Their papers and ensuing discussions include insight into the architect's concern with materials, including the impact of energy on building design:

> "Cost, form and compliance with functional or energy criteria are not separate decisions, but really one decision that you are making at the same time. If one is good at that, one makes all of them good decisions." Cesar Pelli (Crump and Harms 1981, p. 168)
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> "Presumably, efficient architecture would conserve energy. We did that by looking at parts of the building in quite specific ways and we gave them specific functions, so that the notion of efficiency was based on a nineteenth century idea of technology which saw efficiency in terms of a single functioning of single piece.
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> "But what has been focused on here is a different sort of physical issue, representing a different kind of philosophy. It's the multiple use of a given piece of material. How many ways can you get it to function simultaneously?
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> "Looking at the slides of Cesar Pelli's buildings, I was thinking about how much was gotten from any given piece of material. An image, a reflection, enrichment, thermal property, transparency, translucency - all were gotten. Any given piece of material wasn't viewed in terms of any single function, but in terms of a multiplicity of roles.

"I saw Erskine's work in exactly the same way. A given piece of material functioned in a variety of ways, and the notion of specialization of part in order to get the maximum efficiency. I think I saw that sort of thread running through everybody's work.

"When you look at what you are doing in the studio, a more relevant question, it seems to me that what is certainly consistent with what has been said here, is the manipulation of the material of construction, the material of the building. How much are you getting for it when you put it in place? It's a question that interests me a lot, and I keep being reminded how much really good designers can get for that material they are putting in place, and whether you think about that when you put the material in position, at least on paper." Ralph Knowles (Crump and Harms 1981, pp. 166, 167)

"That suggests that any free-standing tower like the Hancock Tower in Chicago does not stand in a thermally symmetrical environment. The discontinuities across the 120-foot deep dimension of that tower make a temperature differential that you would have to go from Chicago to Miami Beach to make in the outside world. Actually, I think you would have to go beyond Miami Beach. This means that, inside that 120-foot depth of the tower, you are trying to correct by purely mechanical means a thermal dimension of 1500 miles! As far as thermal disequilibrium is concerned, that building is 1500 miles deep, not 120 feet.

"Yet our ambition is to make every square foot of each floor equally comfortable. With modern technology we rely exclusively on mechanical means for achieving that equilibrium. My question about all thin-skinned buildings is whether or not this is an optimal solution: whether or not the architecture itself shouldn't take some of the load of correcting this disequilibrium before we call for the sophisticated systems. Another building that Cesar Pelli showed us recognized this fact: the north wall was dramatically different from the south wall visually, because it was different thermally. These are two good examples of how we ought to approach this question. I feel this is one of the great errors of contemporary architecture. Because we are possessed with formal ambitions for aesthetic success, we really produce uninhabitable space and then turn it over to the engineers to make it habitable. An historic function of the architect is to produce habitable space. Until 100 years ago, there wasn't any G.E. compressor onto whose shoulders we could shove this responsibility, so we were compelled to solve this in architectural terms. I think it's a great mistake to use modern technology to escape this obligation." James Marston Fitch (Crump and Harms 1981, pp. 171, 172)

RESEARCH AGENDA WITH PROJECT DESCRIPTION

The panel developed an Advanced Program Scope outline that served as the framework for the research agenda. Basic and applied research are major classifications of the Advanced Program Scope, and materials science and materials design were the areas of particular concern for the panel.

Materials Design is concerned with combinations of materials, the interaction of materials, and the impact of materials on envelope systems and on whole building performance. This part of the Advanced Program Scope will add a new dimension to the consideration of the dominant role materials play in building performance and should stimulate consideration of the complete spectrum of building materials. The use of materials in combination provides a materials system with a performance that is more than the sum of the properties of the individual materials.

A diverse collection of project titles, listed in Appendix 1, was ordered by the panel using the Advance Program Scope as the framework. The panel selected 24 projects for development. Each project description begins with objective and scope statements that set the boundaries and indicates the intended project accomplishment. The next two sections indicate why a project needs to be done and how to go about doing it. The final section lists the research products anticipated. Examples of two project descriptions are provided in Appendix 2. The others are available in the final report, an ORNL document. (Bales 1986)

COOPERATIVE PROJECT MODE

Ideally, federally supported research has broad support from the private sector and professional community. Funding is usually justified on the basis of meeting the needs of the building sector. In addition, federal funds are by policy awarded to the competitive bidder unless there is a unique potential contractor. On a competitive basis, a single best proposal must be selected from those submitted. Frequently a nonwinning proposal will have a unique, desirable feature that cannot be pursued. An alternate to the usual funding procedures is a cooperative project mode.

The initial step in a cooperative project is an identification of a suitable project. It should not be product development as that is a private sector responsibility. A cooperative project begins when DOE/ ORNL seeks out those interested in the research results or when a public call is made for cooperators. Applications are evaluated for technical capabilities and experience, and ORNL issues invitations to form a group to define and undertake the necessary research work for a particular project. At the initial meeting of the group, a general description of the project is offered as the basis for discussion. The group decides whether the proposed project is relevant and then writes a scope and a research plan including a division of resource responsibility and task responsibility. Resources include dollars, in-kind professional services, and equipment. Partners need not contribute equally or provide the same or all resources; some will have strength in only one area, e.g. they may have access to a unique piece of equipment or may be a unique individual.

Careful planning with the consensus of the group is required. A manager, not a researcher, from ORNL takes the lead in the discussions and the eventual project management to ensure impartiality and to expedite progress. It should be clear from the beginning that all research results are to be published, negative as well as positive. The form and style of presentation is by consensus of the group.

It is ORNL's responsibility to act as the focal point for arranging funding, internally and externally. Usually there are contributions from several sources that need to be organized, assimilated, and coordinated. It is also ORNL's responsibility to keep all cooperators fully informed. This may be done with quarterly progress briefings including scheduling and budget updates. Any change in project direction, which is a group responsibility, should be reviewed and approved at the briefings. This group will provide strong direction and cause the researchers to defend work in progress rather than at the conclusion of the project when it may be too late to recognize and take advantage of new suggestions.

One alternative is to use an outside organization to manage the project with ORNL only as a research partner. The outside organization could be an association to which most of the partners belong. In any case, a strong individual manager is needed who can deal with the fiscal arrangements and the technology involved and who can manage a group on a consesus basis.

Cooperative projects are an obvious and significant amplification of effort and resources. Knowledgable people and valuable resources are quickly assembled and focused on a particular issue. Many of the people and resources would normally not be available to a DOE/ORNL project. Specific benefits include:

- continuous and immediate feedback to the researchers while the project is in progress
- sharing of the funding responsibility
- combined concerns on project issues
- combined talent and experience in research
- all cooperators getting immediate benefit of research as it progresses
- drawing together diverse organizations usually separated by proprietary interests
- stimulating the release of proprietary data by the cooperators to obtain project objectives
- prompt dissemination of the results
- open technical interface and a forum for exchanges between suppliers and users of building materials

- project results that are more quickly communicated, understood, accepted and put into use to the benefit of the designers
- in some projects, cooperators from several different building types working together to solve common problems
- accomplishing research that relatively small organizations cannot accomplish alone.

A project that must satisfy several cooperators will inherently be more difficult to manage. Proposals for changes in scope and/or direction are more likely. Specific drawbacks are that the project:

- requires careful planning and coordination of the cooperators by the project manager
- must satisfy many different interests
- has a high risk for over budget spending because of project direction changes requested by the coordinators
- may produce technical results that are considered negative by some cooperator interests. There may be effort to suppress these results.

RECOMMENDATIONS

The panel recommends that the projects that have been selected for complete descriptions be given priority consideration for DOE/ORNL support. In its judgment the completion of that set of projects would significantly advance the state of the art in the understanding of building materials performance and the more effective use of diverse building materials in the design of buildings. Designers could be better building designers with an enhanced understanding of materials and expanded design solutions.

The panel further recommends that the DOE/ORNL program managers adopt the program scope as a first step in advancing the program into new directions. Further support should be given in the development of a statement on the ramifications, implications, and impacts that such a new direction would have in other programs, organizations, and design practice. It should qualify and quantify the advantages of such research.

If the projects considered most urgent by the panel should not be acceptable to DOE/ORNL or if annual funding levels will support additional projects, the list of potential projects in Appendix 2 should be used to identify candidate research opportunities. As research is completed and priorities change, the list should also be consulted. In addition, the panel recommends the use of the cooperative project mode. Its use will stimulate a new attitude about the building materials program and its priorities. A situation will be created that will inherently keep the federal program relevant. Research results will more immediately impact the design of energy efficient buildings.

REFERENCES

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ACKNOWLEDGMENT

This work was supported by Oak Ridge National Laboratory under subcontract 39X-97333V as part of the Building Thermal Envelope Systems and Materials Program. The panel members were Erv Bales, chairman; P. R. Achenbach; George Barney; T. J. Cardenas; Bion Howard; John Samos; Richard Grot; Mort Sherman; Ward Hitchings; and Dan Morgenroth

APPENDIX 1

BUILDING MATERIALS RESEARCH

POTENTIAL PROJECTS LISTING

I. MATERIALS SCIENCE

A. Data Base

1.* Thermophysical properties of concrete and masonry
2.* Thermophysical properties of wood and wood products
3.* Thermophysical properties of material composites
4. Thermophysical properties of sheet glass with surface coatings
5. Thermophysical properties of light-transmitting plastic insulations
6. Properties of movable insulation
7a. Water vapor permeability and temperature coefficient of building materials
7b. Surface adsorption isotherms (water) of building materials
8. Characterize properties of building envelope joint closure materials
9. Sealant properties and compatability
10. Thermophysical properties of materials components
11. Thermophysical properties of "thermal break" materials
12. Development of materials that are heat storing, insulating, and structurally sound
13.* Development of high strength bonding agents
14. Investigate UFFI shrinkage in service in relation to mildew problems
15. Outgassing characteristics of building materials
16. Long Wave emissivity and reflectivity of building materials
17. Develop and establish a series of standard reference materials to use in the measure of thermal physical properties of building materials

B. Modeling

1.* Thermal anomalies modeling techniques (three dimensional heat flow)
2.* Analysis of the combined modes of heat and moisture transfer
3. Determination of data precision and accuracy requirements for models
4.* Characterize dynamic thermal performance of materials and materials combination
5. Characterize a heat transfer model for foam insulations, including aging and temperature effects
6.* Development of model of ground contact heat transfer

C. Test Methods and Equipment

1.* Develop test methods for measurement of outgassing of building materials
2.* Develop tests for coefficient of thermal expansion for composite sections (sample size to be defined by product and application)
3. Develop test methods for reflective thermal insulations
4. Develop a test method for air barriers
5. Develop tests for the accelerated aging of materials
6.* Develop tests for measurement of thermal properties of materials that contain moisture
7.* Develop new techniques for measurement of moisture levels

in materials (see C.8 below)

8. Development of fiber optic sensor techniques for non-destructive observations and testing within the exterior envelop (see C.7 above)
9.* Development of screen technology for replacement of small heat flow meters currently used in the field
10.* Develop a standard test procedure to measure dynamic heat transfer
11. Development of three-dimensional mapping of thermal physical properties of material assemblies
12. Development of test method to measure long wave emissivity and reflectivity values of building materials

D. Design Applications/Laboratory

1. Performance of structural components
2. Performance of moveable thermal insulation
3. Performance of non-corroding fastners
4. Design impact of leachables
   e.g., lime from cement or mortar
   Acid extracts from phenolics
5.* Performance of materials under cyclical wetting and drying conditions
6. Conduct studies on the effect of mass on energy loads in the Gulf of Mexico Region

II. MATERIALS DESIGN

A. Coupled properties - Interaction Data Base

1.* Performance of underground insulating materials
2. Investigate redundancy mechanisms from materials in combinations as used in a building envelope
3.* Development of new high-strength, low conductivity materials to use as ties and lateral reinforcement in concrete, masonry and metal wall panels
4. Performance properties of specific materials composites
5. Development of compatible fire retardants and moisture decay inhibitors
6. Development of high thermal mass plenum walls or floors for nonresidental buildings
7. Comparison of steel studs and masonry backup for brick veneer construction
8. Measure the thermal performance of block walls with various convection barriers within the walls for basements and crawl spaces

B. Design Applications - Laboratory

1.* Effects of moisture absorption and release on thermal properties and long term durability of insulation materials, concrete, masonry, wood and composites
2. Installation techniques for surface material, e.g. vapor barriers, air barriers, reflective surfaces
3.* Design of construction joints of different materials and adjacent joints using the same materials
4.* Good practice guidelines for utilizing materials in building envelopes
5.* Establish a large-scale, controlled environment facility to study performance of materials in combination under dynamic, thermal, moisture, and mechanical stress conditions
6. Integration of building elements and HVAC systems, including the use of air cores in concrete block, precast hollow core slab and metal deck/floor units
7. Correlate mold and mildew growth and prevention technology with building materials physical properties

8.* Measure thermal performance of standard wall constructions to establish current practice
9. Measure the thermal performance of building joints
10.* Determine the effect of inside roof surface conditions on ceiling insulation performance
11. Determine effect of foilface ceiling gypsum board on the attic energy balance and flow of water vapor

C. Proof of Concept - Field Performance

1. Transfer NASA technology in noncorrosive materials for fastners
2.* Transfer NASA technology for improved multipurpose vapor and air barriers
3. Measure performance of materials in combination as foundation and basement insulations

D. Diagnostic

1. Evaluate vapor control practice in a balance between summer and winter conditions, e.g., Florida
2. In-situ measurement of thermal physical properties of materials in combination
3. Develop diagnostic procedures for evaluating the integration of joints and sealants
4. Develop diagnostic procedures for evaluating the dynamic moisture performance of building materials in combination

Note: * indicates those project titles expanded to project descriptions.

APPENDIX 2

Two Example Project Descriptions

1. Title: **EFFECTS OF MOISTURE ABSORPTION AND RELEASE ON THERMAL PROPERTIES AND DURABILITY**

2. Objective: To develop an understanding of the physical process of moisture transfer to and from porous building materials and the effects of the transfer on thermal and mechanical properties. The understanding should be based on analytical modeling and labotarory measurements.

3. Scope: An investigation of all porous building materials would be carried out to determine the effects of moisture transfer and storage on the performance as a single building element and on members of composite constructions. The range of environmental conditions would be those normally experienced in U.S. buildings with a focus on hot/humid climates. An important part of the study is determining the rates of changes under different relative humidity levels.

4. Problem Significance: All building materials, single elements and composites, experience an exposure to moist air at varying levels of relative humidity. It is clear that moisture is transferred to the materials and is stored as water. If conditions are proper, the atroed water will either be below a critical level or will be released back into the air. As buildings are designed and built to be more energy efficient, moisture effects become more pronounced. Although there is some laboratory data on levels of moisture stored, particularly in wood, the process of transfer and storage is not understood. As new materials and new uses of materials are considered, it is necessary to understand the moisture physics to avoid bad design. The project would investigate that transfer process including the complex physics of the interface boundary between the moist air and a porous material surface.

5. Technical Approach: An analytical and laboratory study would be conducted with the following tasks:

   Task 1. Survey the literature for available physical data on the properties of building materials as a function of moisture levels.

   Task 2. Assess the literature for analytical models in other applications that might be applicable to building materials. Identify or develop a preliminary model.

   Task 3. Design laboratory tests to measure material properties required by the analytical model. Measure the needed data on a series of porous building materials. For example, the surface to volume ratio is necessary to predict how much water can be attached to the internal surfaces.

   Task 4. Use the data to develop a final analytical model.

   Task 5. Investigate the performance of several porous building materials with the model. Use actual environmental conditions and consider design situations.

   Task 6. Develop guidelines for use of the materials by the designer and builder.

6. Research Products: The project would result in a model of the moisture transfer and storage processes, a laboratory data base, and guidelines that could be used in design publications such as the ASHRAE and AIA handbooks.

1. Title: **DETERMINE PERFORMANCE OF MATERIALS AND COMPOSITES UNDER CYCLIC WETTING AND DRYING CONDITIONS.**

2. Objective: To evaluate the effect of climate-induced daily, seasonal and annual cycles of wetting and drying of building materials and composites on their performance in building components.

3. Scope: The research should include representative concrete, masonry, wood, plastics, insulation, and composite materials. It should investigate moisture sorption and desorption processes in walls, crawl spaces and ceiling/roof constructions. The construction should be exposed to a sequence of diurnal cycles simulating the winter and spring seasons climate in the U.S. under air-conditioned and non air conditioned interior conditions. The research should determine and evaluate the effects of wetting and drying cycles on thermal resistance, fire properties, durability, and dimensional change.

4. Problem Significance: Experience with wetting and drying of building materials under use conditions has not produced useful conclusions on the tolerance of various materials for cyclic moisture stroage or surface wetting and drying. Most existing good practice guidelines and regulations in use in the U.S. are designed to prevent or minimize condensation on hidden or exposed building materials. Mold and mildew growth on both interior and exterior building surfaces have been observed in various building developments. Research on Canadian structures in colder climates indicates that seasonal wetting and drying of wood members in building does not cause appreciable deterioration, if the members that become wet during the winter dry out before warm outdoor temperatures become prevalent in the spring. Generally what is known is qualitative and not quantitative.

Carefully documented research on the effects of cyclic wetting and drying of building materials would identify the geographical areas of climate conditions where vapor retarders could be minimized and would provide design guidance on the prevention of mold and mildew growth, corrosion, excessive dimensional change of materials, and accelerated deterioration of organic building materials.

5. Technical Approach:

Task 1. Survey and assess the qualitative information that has been published by the several research groups concerned with specific incidents or conditions.

Task 2. Evaluate the cyclic period and extremes of temperature and humidity to determine critical values for each material. Determine the number of cycles in a year on a regional basis. Determine the impact of daily, solar driven cycles.

Task 3. Using the cycles from Task 2, analyze the performance of materials undergoing the changes.

Task 4. Conduct laboratory testing to substantiate the analysis and document material performance.

Task 5. Evaluate materials in-situ for several building types, depending on the material.

6. Research Products: The data and analysis could be used in the development of models used to evaluate attic spaces, crawl spaces, and wall spaces under the same cyclic conditions. A standard test procedure for characterizing materials under dynamic conditions could also be developed.