Building Enclosures: A Strategy for NSF Support

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Abstract

This paper reports on the activities of one of the Focus Area Groups, i.e., the Building Enclosure focus area, at the NSF workshop held in Orlando on 12-14 February, 2004. The objective of the report is to synthesize the discussion of the participants and to document their strategic recommendations. An attempt was made to identify those activities involving housing that are of mutual interest to the parties involved, namely NSF and the universities. There were seven participants in this group and each contributed a paper. It was necessary in this report to define and expand upon building enclosures because of the need for NSF and the universities to better understand and appreciate the relative and singular importance of the building enclosure and its performance. Reference was also made to the DOE Roadmap on Building Enclosures.

Keywords: Building Enclosures, Building Science, NSF, Strategic Plan, Universities, Housing

Introduction

To their mutual credit, the Consortium of Housing Research Centers and the National Science Foundation recently organized and conducted a workshop to develop a joint research agenda for residential construction. The workshop took place over the period 12-14 February, 2004, in Orlando, Florida.

This meeting was important because it was an occasion for dialogue not only between this very influential Federal agency and the universities but also among the universities themselves. As some 30 universities were represented, it was an opportunity for many universities to become familiar with the activities of the Consortium.

Residential construction, i.e., low-rise one and two-family housing, contributes about 1.3 million new housing units each year, while the existing housing stock consists of more than 113,000,000 housing units. Housing is a large and complex field, and it is necessary to identify and focus on well-defined and manageable topics that are of mutual importance to NSF and the university community. Accordingly, five focus areas were identified, and this paper reports on the activities of one of them, i.e., the Building Enclosure focus area.

The objective of this report is to synthesize the discussion of the Building Enclosure Focus area participants and to document their strategic recommendations. The scope of the report goes beyond this primary objective because it is also necessary to attempt to do the following:

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1. Identify those activities involving housing that are of mutual interest to the parties involved, namely NSF (and possibly HUD) and the universities—or, more precisely, those groups or individuals who have a commitment to some aspect of housing. Note that the Consortium as well as most of the invitees was mainly but not exclusively technically oriented. The building enclosure is largely a technical area.

2. Define and expand upon building enclosures. In contrast to, say, structural or mechanical engineering, few U.S. universities focus on or even teach Building Enclosures and the related Building Science. There is a need for NSF and the universities to understand and appreciate the relative and singular importance of the building enclosure and its performance.

3. Take into account the relevant contributions of two national organizations, namely DOE and the NAHB, that have recognized the importance of the building enclosure and have devoted considerable effort and funding to developing "Roadmaps." These Roadmaps are much more than R and D strategies, and should be given due weight.

The approach taken in this report is first to address item 1 above, to consider item 2, and to report on the activities of the focus group. Finally, the group's recommendations are discussed within the context of item number 3 above.

The Mutual Interests of NSF and the Universities in Relation to Housing Technology

To say that until the joint HUD PATH/NSF program came into being some four years ago, the NSF was not interested in housing is to overstate the case. NSF has always funded materials research as well as structural and mechanical engineering. However, there has been little or no specific focus on the technical needs of the housing industry as such.

The universities, on the other hand, do address housing. Many universities have strong non-technical programs in housing economics, housing statistics, social housing, the sociology of housing, real estate, etc. Some universities, especially the non-ABET programs in building construction or construction management; do cover some of the technical aspects of housing. However, most mainstream engineering schools do not have a perceptible housing focus in their Civil Engineering, Mechanical Engineering, or even Architectural Engineering departments. Of course many undergraduate courses have relevance for housing, but focused efforts to address the particular needs of the low-rise housing industry are few and far between. Clearly both parties have some way to go if housing technology is ever to become a significant, fully serviced focus of university endeavor.

To identify mutual interests, consider Table 1 which was developed to identify attributes of the housing process such as phase, term and context and, then, using a simple weighting system, to arrive at aspects of common interest. With some allowance for personal opinion and bias, any topic with a weighted joint relevance of 3 or more would seem to qualify, and topics with weights of 5 or 6 should be accorded high priority.

Solely from a joint NSF-University perspective, it would seem that we should be concentrating our efforts on:

- Basic and applied research, with less effort on the developmental aspects

- A horizon of 10 years or more
- Knowledge, technology transfer, and education within the university
- Industrial considerations, i.e., collaborating with industry in a variety of ways, in particular to resolve problems and to support and push the evolution of housing technology. Monitoring may well be an important area for University involvement.

Table 1: A general developmental strategy for housing technology

ATTRIBUTE	ASPECT			UNIVER-SITY	NSF	WEIGHTED JOINT RELEVANCE
PHASE – IN THE HOUSING PROCESS	Pre-Implementation	Research (Basic and Applied)		***	***	6
		Development (Concept to Product)		**	*	3
		Demonstration (Proof of Concept, etc.)		*	-	1
	Implementation	Information Dissemination		-	-	0
		Marketing		-	-	0
		Technology Transfer		**	*	3
	Post-Implementation	Training: Trade		*	-	1
		Training: Professional		*	-	1
		Education		***	*	4
		Monitoring and Improvement		***	*	4
TERM (Duration)	Near-	0 – 3 Years		*	-	1
	Mid-	3 – 10 Years		**	*	3
	Long-	10-20 or More Years		***	***	6
CONTEXT AND ISSUE	The Technology	Primary and Basic Technical Features		***	***	6
	Considerations:	Industrial		***	**	5
		Regulatory		**	-	2
		Social		*	-	1
		Economic		*	**	3
		Barriers	Technical	**	*	3
			Liability	*	-	1
			Market	-	-	0
			Process	*	-	1
			Regulation	*	-	1
			Knowledge	***	**	5
		Incentives	Financial	*	-	1
			Energy Conservation	**	*	3
			Problem Resolution	**	**	4
			Progress (Evolution)	*	***	4

Code: Relative Significance
*** Highly Relevant, Essential
** Advantageously Relevant
* Relevant
- Priority for others, or not relevant

Joint Relevance: 0 to 6 in increasing order

This table also identifies those topics that are largely outside the purview of NSF. This does not mean that such topics are not important, but rather that some other agency or organization plays, or could play, a lead or partner role. Energy conservation, for example, is an issue of national importance but one that falls largely within the purview of DOE rather than NSF.

The Building Enclosure

A building, any building, comprises four physical parts: the superstructure, the building enclosure, all the service systems, and the building fabric, i.e., everything not incorporated in the other three physical parts. For housing, especially low-rise detached housing, the building enclosure is uniquely important. For instance, in the case of a one-story, ranch type house with a slab on grade at grade level (i.e., no below-grade basement or crawlspace), the superstructure is wholly within and integral with the building enclosure. The component parts for a representative building enclosure are shown in Figure 1.

At this point it is necessary to set out, in generic terms, what building enclosures encompass, i.e., what are they made up of, what purpose they serve, and so on. First, the building enclosure is the constructed separator between the exterior environment and the indoor environment. The exterior environment is more than just the weather, and the indoor environment is more than the conditioned (or non-conditioned) air in the internal space involved. Note that any intermediate floors and walls that separate interior environments are integral parts of the building superstructure, or they are parts of the building fabric, or they are a mixture of both.

The building enclosure has to serve numerous functions, and these may be categorized as:

?? **Support** functions in relation to structural forms of loading

?? **Control** functions in relation to environmental forms of loading

?? **Finish** functions in relation to the forms of surficial loading on each side of the enclosure element

?? **Distribute** functions to accommodate the consequences of interfacing with the service systems, including the utilities, and their distribution within or through the enclosure or both.

The building enclosure has, of course, to be designed to accommodate all relevant loadings and all likely combinations thereof, and to satisfy all relevant attributes. The main dimensions of this generic design process are shown in Figure 2. In reality, however, the building enclosure on most residential buildings is not designed, and it is certainly not designed with either the rigor or the comprehensiveness of Figure 2.

Most aspects of the residential building enclosure, including any integral structural elements, are chosen on the basis of the previous house that was built, or recent experience, or tradition, or a mix thereof. In fact, and this is likely to continue, building enclosure components in production and custom housing are “designed” and improved and, thus, evolve on a collective basis. Change in the housing industry comes about largely as a result of regulation, cost savings, and innovation that is economically viable in the short term. It is quite likely that the main reason for the recent interest in building enclosure performance dates back to the so-called energy crisis of 1974 when energy conservation, i.e., thermal insulation and air tightness, was introduced into the building codes. Because these changes caused the enclosure to cross a number of behavioral thresholds, moisture and the attendant building performance and occupant health problems have become matters of national importance. Of complementary importance were the growth of condominium ownership and the ability of owners, for the first time, to be able collectively to sue the developers/builder.

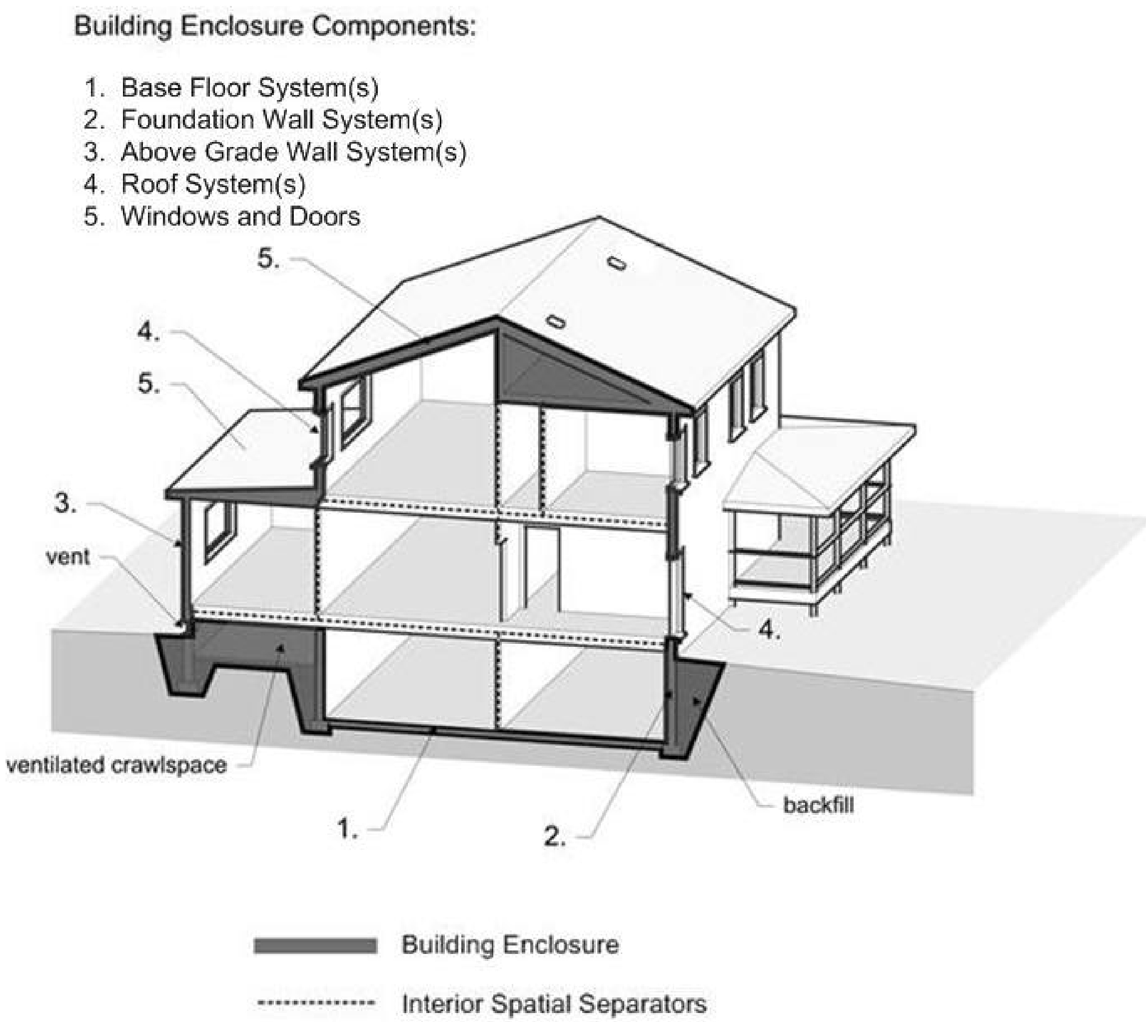

Figure 1: Building enclosure components

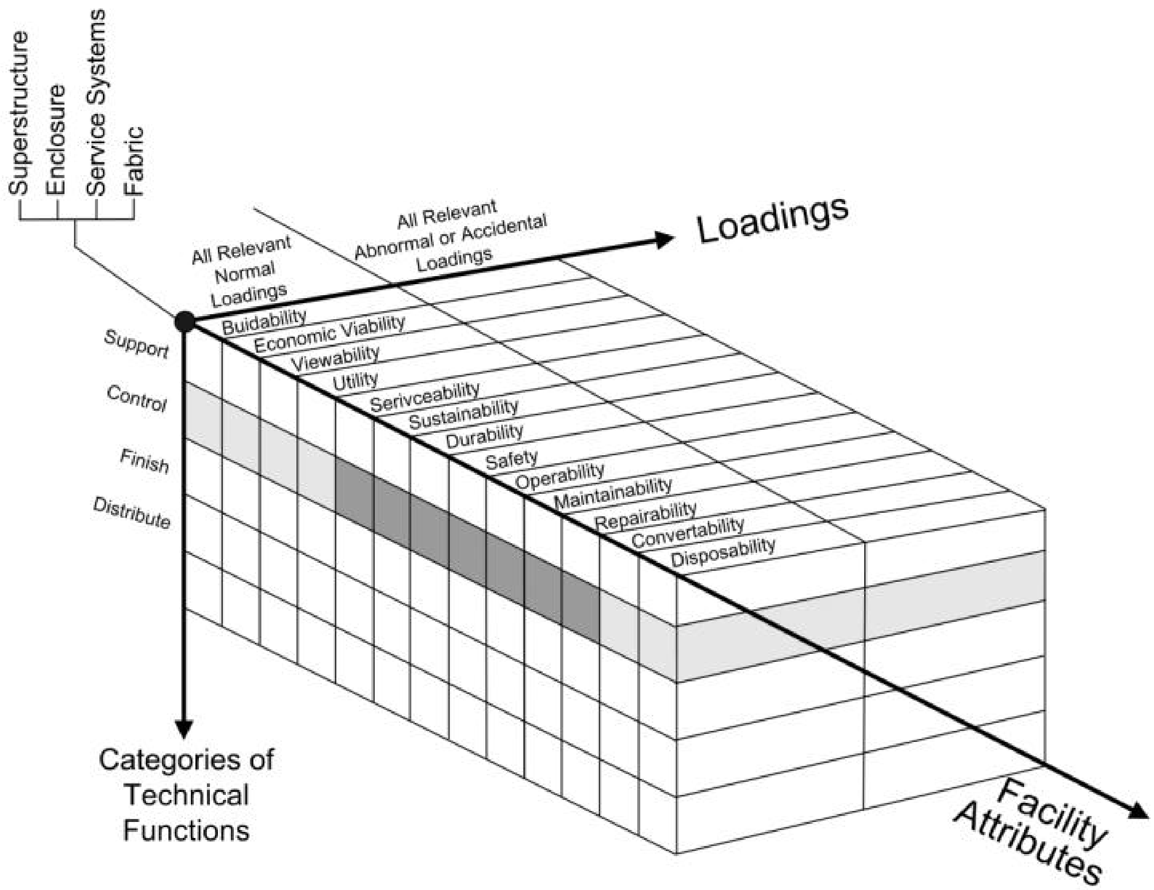

Figure 2: The dimensions for design and the performance of buildings

In housing, as well as for buildings in general, a technical paradox exists: the building enclosure is seldom actually designed (i.e., with any analytical rigor), yet it is a complex assembly that accounts for a major share of the new-construction dollar. It is also visible and architecturally critical. One "after-market" measure of the importance of the impact of this paradox could be the amount of money spent on the maintenance, remediation and repair of enclosures and the consequences (money and health) for people who have been, in one way or another, impacted by poor performance.

To comprehend the complexity of the components of any building enclosure, consider the elevation through the very common residential wall system shown in Figure 3. This representative framed exterior wall is composed of a number of layers (8, possibly 12). There are three (possibly five) membranes, one air layer and four (possibly six) thicker and stiffer layers. Without even considering the two surface films (inside and outside) commonly used to represent the thermal performance at each exposed face, this multi-layer wall would be difficult to analyze even if we knew all the relevant properties for each layer. Each layer acts interdependently, and the composition of each layer varies from solid to composite, comprising more than one material or even hybrid (e.g., the stud space insulation and the wood framing.). This hierarchy of constituents is shown in Table 2.

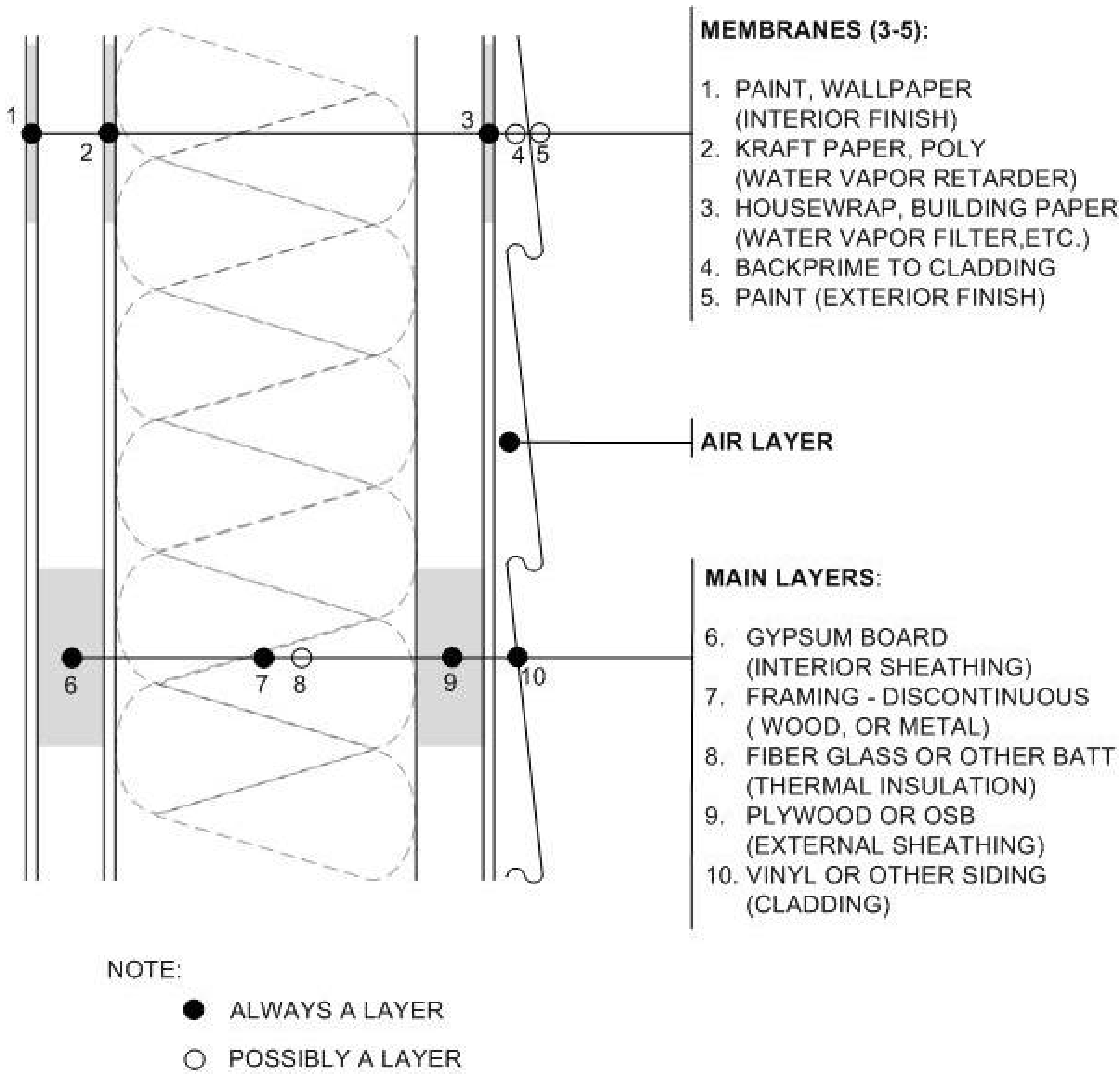

Figure 3: Representative framed wall system

Table 2: Hierarchy of Considerations

Level of Consideration	Component Parts	Number of Parts	Commentary
Building	Superstructure Building enclosure Service systems Building fabric	1, with 4 parts	This paper is limited to the building enclosure which is not independent of the other component parts.
Building Enclosure	Roofing system(s) Wall system(s) Windows Doors Below-grade wall system(s) Base floor System(s)	1, with 4 parts	Intermediate floor systems are part of the superstructure and, with internal partitions, also involve the building fabric. Windows and external doors are integral with the wall system.
Layers	Sheathing(s) Wythe(s) Thermal insulation(s) Cladding Membrane(s) Air layers(s)	These are the major layers: 3, often more 2, often more Often 1 or more	Thick, often board-type layers Relatively thin, often flexible Deliberate spaces, cavities
Materials	Wood: solid composite Metal: Cementitious: solid composite Gypsum-based Bitumen-based Plastic: PVC Other Paper-based Silica/glass-based Etc.	Many different materials and composites in many forms and combinations	Natural or synthetic, and on-site or offsite, and composite (material mix) or hybrid (layered mix)

Table 3 was developed for this report to demonstrate the diversity of those layers labeled "membrane." Membranes of this sort and their properties—especially, their installed performance—are not well understood. Note that for the wall-related membranes listed, at least four major industries are involved. Membranes in exterior walls conservatively represent 15-20 billion square feet of product per year for new housing alone. Given that these membranes together with the thermal insulation are the control elements for most of the hygrothermal or environmental loadings, they are also very important constituents of a wall and, for that matter, the whole enclosure. As shown, they all serve multiple functions. This table of wall membranes is indicative of some of the technical, educational, and economic opportunities for NSF support for work at any university.

Table 3: Membrane layers in exterior walls: location, type, functions and relevance

Name and location of Membrane	Materials	Control Functions	D.F.[1]	R.S.[2]	Comment
Interior membrane to internal sheathing or wythe	Paint	Water vapor retarder/filter	?	P	Visible Finish
	Wallpaper	Air barrier	?	S	
		Water barrier	?	I	
External membrane to internal sheathing or internal wythe	Kraft paper	Water vapor retarder/filter	?	P	
	Polyethylene	Air barrier	?	P	
	Mod. Bitumen	Water barrier	?	I	
Exterior membrane to exterior sheathing or internal wythe	Housewrap	Water vapor filter/retarder	?	P	
	Building Paper	Drainage plane	?	P	
	Bitumen	Barrier to penetrant water	?	P	
		Air barrier	?	I	
		Face of ventilation chamber	?	S	
		Face of air pressure chamber	?	S	
		Radiant heat flow retarder	?	S	
Interior membrane to cladding (backprime)	Paint	Drainage plane	?	P	
		Water vapor retarder	?	S	
		Face of ventilation chamber	?	S	
		Face of air pressure chamber	?	S	
Exterior membrane to Cladding[3]	Paint(Coating)	Drainage plane	?	P	Visible Finish
	Sealer	Water vapor retarder	?	S	
		Water barrier	?	P	

Note: 1. D.F. - Direction of any flow
2. R.S - Relative significance: P-Primary, S-Supplementary, I-an Issue
3. This membrane is applied to the cladding but that does not necessarily mean that the in-place cladding in itself is a perfect barrier to water.

Table 3 can also be used to make the following points about building-enclosure-related R and D.

?? When conducting R and D on enclosure materials, those involved should have some idea of all the relevant functions to be served and how the layer is to be attached.

?? Someone involved should be familiar with the hygrothermal mechanics of the enclosure elements and should have some ability to comprehensively analyze the behavior of each assembly.

Focus Area Presentations and Discussion

Focus Area 3, nominally titled Building Enclosures, involved researchers from eight different institutions. This group met for individual presentations and discussion on Friday and Saturday, February 13 and 14, 2004. On February 14, a joint meeting was held with Focus Area 2: Structural Design and Materials. Later that day, a general session was also held at which the various group leaders made a short presentation on behalf of their group area.

Table 4 lists the members of Focus Area 3, the titles of their presentations, their affiliation, and contact information. The topics covered by the eight speakers could be grouped as follows:

?? Enclosure component considerations (John Little)

?? Hygric or hygrothermal concerns (mainly moisture and thermal control) (Chandra, Huelman, and Burnett)

?? Materials (Wu, Shah, and Chandrashekhara), and

?? Hazard loadings and the performance of the building enclosure (Grant)

This group was a diverse one, comprising four senior professors, three younger faculty members, and Rose Geier Grant from State Farm. Her knowledge of both insurance and related housing needs provided a different perspective, certainly a larger and more holistic viewpoint than that of most of the university-based members.

The papers are reproduced in a companion publication, and most of them were also the subject of a poster presentation. The following is a list of particularly interesting points that were made:

1. John Little was concerned about the significance and mathematical modeling of VOCs from Structural Insulated Panels (SIPs) and the mounting awareness of loss of productivity as a measure of the impact and the broader significance of air quality. He confirmed the importance of water vapor transport across layered building enclosures as well as the simultaneous transport of heat (energy) and mass (VOCs) as fruitful areas for study.

2. Subrato Chandra addressed a number of issues peculiar to hot, humid climates with particular relevance for manufactured housing. Whether or not to ventilate crawlspaces or attic spaces naturally is a "hot issue" at present. There are also issues with slab-on-grade at grade floor systems. He stated that "mold-related costs are skyrocketing in Florida." It is

evident that better moisture control across and within the building enclosure is one key to better housing, especially in the fast growing southeast.

3. Pat Huelman, who has had first-hand experience of moisture and energy-related problems with basements and crawlspaces in Minnesota, emphasized the need for a better understanding of moisture-related performance and the need for sustained work on hygrothermal modeling.

4. Eric Burnett reported on a major project to study the relevance of natural ventilation to promote the drying of exterior wall systems. He remarked on the importance of controlled natural ventilation for residential construction in general, i.e., whole house conditioning, roofs, basements and crawlspaces, and wall systems, and the fact that this science is not well understood. He also noted the need for cooperation across disciplines if substantive progress is to be made.

5. Qinglin Wu spoke to the development of durable (mold-proof and termite-resistant) wood-based products. Mold and termites are two very important issues for the future of the wood industry. He was largely concerned with preservative treatment. He also commented on the need to develop tests and models for mold, termites, and other forms of loading.

6. Surendra Shah and Katherine Kuder discussed their work on the development of fiber-reinforced cementitious composites. The success in North America of the Australian-developed Hardiplank cladding certainly underlines the importance of their work. It was interesting that considerable effort is being devoted to nailability. Ms. Kuder went to some trouble to provide relevant economic data.

7. Dr. Chandrashekhara is involved in investigating the suitability of using bio-based materials in building enclosure assemblies. In particular, the use of pultrusion to manufacture product made from vegetable-oil-based resins (such as soybean, linseed oil, etc.) was seen to be the way to go.

8. Rosemarie Geier Grant pointed out that the building enclosure was critical to the insurance industry. First, the building enclosure usually has to bear the brunt of hazardous loadings (hurricane, tornado, blast, flooding) as well as regular forms of loading (high wind, rain, weather, etc.) and any damage has to be made good. If the enclosure is breached, then the consequential water damage tends to be extensive. Moreover, mold insurance is now difficult to obtain. Given the times, the enclosure also has to accommodate both internal and external blast: especially the latter because the enclosure is the main transfer mechanism for the impact on the superstructure of the building. She also mentioned that insurance rates and policies are, at long last, starting to reflect real costs and actual conditions. She stated that consumers may start to link high insurance rates and policies with poor performance of the building enclosure.

Table 4: Focus Area 3, Building Enclosures: Group member, presentation and affiliation

Name	Paper Title	Organization and Email
John C. Little (and A.T. Hodgson)	Structural Insulated Panels – Sustainable Design Incorporating Impact on Indoor Air Quality	Virginia Polytechnic Institute and State University Email: jcl@vt.edu
Patrick Huelman (and Marilou Cheple)	Hygrothermal Performance of Basement Foundation Systems	University of Minnesota Email: huelm001@umn.edu
Subrato Chandra (and others)	Alleviating Moisture Problems Hot, Humid Climate Housing	Florida Solar Energy Center Email: subrato@usf.edu
Eric Burnett (Leader)	Ventilation Drying in Enclosure Wall Systems	Penn State University Email: efburnett@psu.edu
Rose Geier Grant	Opportunities for Improving Overall Building Performance through the Selection of Natural Hazard Resistant Attributes for Building Enclosure Materials	State Farm Insurance Companies Email: rose.grant.gsxj@statefarm.com
Qinglin Wu	Preservative-Treated Structural Wood Composites for Durable Home Construction	Louisiana State University Email: wuqing@lsu.edu
Surenda P. Shah (and others)	Extruded Fiber-Reinforced Composites for Building Enclosures	Northwestern University Email: s-shah@northwestern.edu
K. Chandrashekhara	Energy Efficient and Sustainable Building Enclosures Using Bio-Based Materials	University of Missouri-Rolla Email: Chandra@umr.edu
Katharine G. Kuder acted as Recorder for the meeting		Northwestern University Emailk-kuder@northwestern.edu

The group had some lively discussions. One point that seemed to provoke group discussion was the realization that most enclosure components (roof or wall either above-or below-grade) are a rather complex, multi-layer assembly, sustaining numerous forms of loading (see Figure 3). The layers could be thick or thin (a membrane); all the layers are interdependent and serve multiple functions. It was agreed that one developmental objective should be to reduce the number of individual layers and make the assembly thinner and simpler, but also to better understand their collective performance.

Another topic that was pursued with enthusiasm was provoked by the realization that sensors and transducers have never been more readily available or less costly. Moreover, the acquisition and manipulation of data, even at remote locations or over long distances, is feasible and relatively simple and inexpensive to accomplish. Accordingly, the overall knowledge or informational needs of the builder, the buyer, the occupant, the building scientist, and the research community, can, for the first time ever, be met. Some of these needs are as follows:

- ?? An archival record of contract documents (drawing, details, specifications, schedule, costs, change orders, etc.) could be maintained by builders and developers.

- ?? Information on materials, equipment, revenues, etc., could be preserved for every house.

- ?? Comprehensive records of materials, equipment, etc., could be maintained for use by both builder and occupant.

- ?? Real-time records of weather, maintenance and operating issues, their cost, liability, problems, etc., could be developed and maintained.

- ?? In-service monitoring of conditions inside and outside the enclosure. This information could be used to control space conditioning needs or used for purposes of providing a record of good performance.

For the first time, it is possible to provide detailed feedback over the longer term for houses. There are many opportunities for research and commercialization with regard to creating this ambitious data base which could have a major impact on the future of housing. It was suggested that NSF be approached immediately to undertake a series of small projects to explore and expand upon this possibility.

Group Recommendations

The final recommendations of the focus group were presented as a list, as follows:

1. **The overall need**. Complementary progress should be pursued on research (R, D and D) and education (university) and training (professional and other client groups) in building science and building enclosures.

2. **Intelligent (holistic) design of building enclosure systems is needed and should encompass:**

   Informational / knowledge needs:
   - Functions
   - Loadings
   - Material properties

   Analytical tools
   - Modeling of interactions between layers
   - Hygrothermal modeling

   Material innovation
   - Improvement of existing materials
   - New material development
   - Chemical modification to enhance durability (bio, fire)
   - Reinforcing fabrics for the appropriate matrix

Monitoring, Feedback and Information Data Base

- Conductive fiber to detect moisture
- Sensor Development and Utilization
- Structure and Establish Data Base

Attribute concerns

- Durability
- Sustainability
- Dynamic (smart) enclosures
- Maintainability
- Operability

3. **The "big" connections need to systematically researched, documented and taught** (e.g., continuity of function, practical realities, examples, etc.
   - Roof – exterior wall junction
   - Wall – Floor-foundation wall junction
   - Footing–slab-foundation wall (below grade) junction

4. **Information; generation, storage, management, usage and feedback (monitoring data and sensing interactions) needs to be pursued.**

Information

- Interactions of enclosures, environment, and people
- Air quality - productivity and health
- Microclimate through GIS, weather information, soil conditions, water table, frost depth
- Development of a Weather Atlas for buildings (macro- and micro-level data)

Phase-related data

- Design phase: drawings, details, specifications, contract documents
- Construction phase: material data, QC info, commissioning documentation
- Occupation: appliances, etc.: warranties, etc., payment records, insurance costs/need and house inspection
- Operational phase: Dynamic Control (t, rh, set-backs, CO, CO_2, smoke (fire), security, nano-climates, etc.)
  - Passive information
  - Active information

Strategies, Particulars and Priorities

It is remarkable that, at this point in time, 2004, neither the NSF nor the universities (with some notable exceptions) have had any focused concern for Building Enclosures in general, let alone the house enclosure. The one federal agency that has clearly recognized their importance, albeit largely from an energy-consumption perspective, is the Department of Energy. In May 2001, after considerable time and effort, and with help from A. D. Little, DOE produced a Building Envelope Technology Roadmap. This effort at strategic planning was largely directed at residential building. It is necessarily a more comprehensive and general plan than the HRC Consortium or this NSF workshop could produce.

The DOE Roadmap is an important document and highly relevant to our focus area. First, their vision was much broader; second, a great deal of money, effort and time was devoted to this exercise; and, third, it involved industry as well as the non-university-based R and D agencies. This roadmap is valuable because it develops strategies as well as identifying particulars and priorities. From the perspective of the universities, NSF, and the Workshop Building Enclosure focus area, the following conclusions are particularly important.

(i) Five **barriers** were identified in the Roadmap, namely:

1. Lack of education/awareness
2. Non-systems approach to building envelope construction
3. Shortage of skilled labor
4. Absence of total system performance measurement
5. Difficulties for new and emerging technology to achieve building code acceptance.

All of the above may be blamed on either a lack of education/training/knowledge or the current process (the way we do things) used for construction or both. While none of these factors would seem to have much to do with the NSF, all five certainly have something to do with the universities: mainly the lack of basic technical education and partly the paucity of R and D.

(ii) Six **strategies** to overcome these barriers are then proposed, three of which are highly pertinent.

1. Promote education/outreach along the construction value chain (their words – not sure if either NSF or the Universities are considered part of this chain)
2. Build a platform for collaboration. This strategy specifically identifies the need for industry/government/university collaboration.
3. Expand the skilled workforce.

A sixth strategy, i.e., to develop, evaluate and promote the adoption of building envelope materials, systems and design and process techniques, was added. Perhaps reflecting how little the universities have so far contributed to building enclosure technology, the complementary text contains no mention of any role for the universities in this strategy.

(iii) The Roadmap also identifies, largely on the basis of an industry survey, viable and prioritized technical needs (Table 5). While I might have some reservations about this table, it is important. It attempts to account for risk, it is weighted on the basis of numerous attributes, and it characterizes particular needs under four headings:

?? Materials
?? Systems
?? Design/process
?? Performance

I would have preferred to categorize Building Enclosure needs as follows:

A. Technology	B. Process	C. Educational
1. Materials 2. Sub-systems ?? Windows ?? Doors 3. Systems ?? Roofing ?? Above-grade wall ?? Below-grade wall ?? Base Floor 4. Special spaces e.g., Crawlspaces, basements, attics, etc.	1. Design 2. Construction and assembly 3. Maintenance, remediation, repair 4. Operational performance	1. Professional 2. Trade 3. Facilitator/regulator 4. Undergraduate and graduate technical students

This DOE Roadmap list is important, especially when the barriers and strategies are also taken into account. Many of the priority items listed would qualify for support by NSF and university involvement.

The focus area list of NSF-related priorities also places a very high priority on education and training. It uniquely identifies the potential for the use of a comprehensive information and related data base developed by continuous monitoring and updating. Both lists emphasize the need for more and better funded support for work on building enclosures.

Conclusion

This exercise in planning on behalf of both the NSF and the Consortium of Housing Research Centers has been an interesting and stimulating exercise for all the participants in Focus Area 3. Preparing this report on Building Enclosure needs has been instructive. The report presents a reasonably comprehensive overview that, without prioritization, identifies those needs that are of mutual interest, i.e., what the NSF could fund and what the Universities could do and possibly obtain NSF support to do so.

No single issue or project has been selected as of being of transcendental or national importance. The one common underlying need is educational and this involves more than NSF and the Universities although both have a role to play and an important stake in this chosen focus area, namely residential building enclosures.

Table 5: Building enclosure needs based on an industry survey (DOE Roadmap)

MATERIALS	Adaptable	Affordable	Durable	Energy-Positive	Environmental	Healthy/ Comfortable	Intelligent	Applicable in Retrofit
Air Vapor Barriers		•	•	•	•	•		•
Advanced Insulation		•		•	•			•
Advanced Aggregate Materials				•				
Disaster-Resistant Materials		•				•		•
Moisture-Control Materials		•		•		•		•
Nontoxic Materials					•	•		•
Radiant Technologies				•				
Resource-Efficient Materials		•		•	•			•
Cellular Building Components	•		•	•				
Fabric Technology			•	•			•	•
Intelligent Building Materials	•		•	•	•	•	•	•
SYSTEMS								
Rain Screen				•	•			
Double Envelope				•				
Advanced Foundations		•	•					
Crawl Spaces		•	•		•			•
Energy Services/Supply				•	•			•
Envelope Component Integration	•	•	•		•			•
Roof/Attic Systems		•	•		•			•
Advanced Panel/Prefabrication	•	•	•	•	•			
Intelligent Envelope Systems				•			•	
Super Walls			•	•			•	•
PROCESS/ DESIGN								
Daylight/Passive Solar Design			•	•	•	•		•
Advanced Framing		•		•	•			
Design Tools	•	•	•		•	•		•
Design for Adaptability	•				•			
Modular Coordination	•	•	•		•			
Natural Ventilation/IAQ		•	•		•	•		
Recycling/Reuse Processes		•			•			•
Regional Design		•	•		•	•		•
Automation		•		•				
Design for Intelligence			•	•	•	•	•	
PERFORMANCE								
Performance Modeling/Testing		•	•	•	•	•		•
Performance Monitoring/Testing		•	•	•	•	•		•
Performance Rating Criteria		•	•	•	•	•		•

Low Risk: Few technical unknowns; within respondent's R&D budget

Medium Risk: Some technical unknowns; some co-funding

High Risk: Many technical unknowns; significant co-funding

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