Supplemental Data #1

A Review of Programs Embracing a Whole-House or Systems Approach for Housing

February 2004

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Abstract:

The following report is the result of an extensive search into whole-house system interactions, definitions, as well as past and on-going programs that have embraced systems design for the home. The report also provides a collection of information regarding current home subsystems and home system definitions. Attachment A identifies and discusses government programs and trade publications, while attachment B consists of scientific and technical literature. This report is part of Phase I efforts under a PATH program to assess the feasibility of a whole-house systems calculator. Future work under Phase II of this program will expand on this information to address specific systems and subsystems.

Introduction

The focus of this literature search and analysis is on government agencies with housing responsibility, the major trade press that typically covers housing, building code documents, and scientific journals and other technical literature. It will be expanded upon in later work by VA Tech and IBACOS to include Building America and related programs that have an energy or environmental focus.

Literature from the following specific organizations was reviewed for this report:

- U.S. Department of Energy programs (PNL, LBNL, NREL, and ORNL)
- U.S. Department of Housing and Urban Development
- U.S. Environmental Protection Agency (Indoor Air Division and Energy Star)
- Forest Products Laboratory
- National Institute of Standards and Technology
- Journal of Light Construction
- Builder and Big Builder (Builderonline.com)
- Professional Builder, Professional Remodeler, Luxury Builder (Housingzone.com)
- Fine Homebuilding
- Home Energy Magazine
- Canadian Housing and Mortgage Corporation
- Institute for Research in Construction (part of NRC-Canada)
- Canadian Housing Information Center
- International Code Council
- Various building science journals

Searches were conducted using both electronic means, by reviewing library holdings, and through communications with experts in the housing and research fields. Electronic searches included use of general internet search engines, search engines internal to specific agency web sites, and internal databases of the organizations. Key words used in the searches included housing, hurricanes, seismic, wind, standards, buildings, building technology, HVAC, walls, moisture, systems, performance, whole house, systems approach, systems thinking, systems design, housing research, and similar terms.

One issue that became apparent rather quickly is that it is rare to find a document that addresses systems effects which also contains these or similar keywords. The types of system interactions that are of interest for our work are not typically the primary focus of the works in which they are presented. In fact, search terms such as “whole house” and “systems approach” rarely resulted in hits, and most often, these were not relevant or poorly documented works. To avoid the necessity of reviewing the universe of documents from a particular agency, we frequently narrowed the review down through discussions with individuals in the agencies or by focusing the search on documents written by authors we know have performed relevant work.

Summaries of the relevant documents are attached. Where no documents are reviewed for an organization, it is because none were found to be relevant or multiple other works had already been identified that supported the same findings. In addition, the building codes were identified for the systems definition task, but they are not described in the attachments.

The next sections of this draft report address how the literature review relates to the tasks in Activity 1 (Tasks 6, 7, and 8) from the Phase 1 project. These results will be used in part as a starting point for the Phase 2 initial tasks.

Task 6. Identify Current Subsystems

The primary objective of this task is to document the status of subsystems by describing the different components in the home building process and definitions for these systems.

Initial findings from Literature Search and Review

There have been multiple approaches used to define the house in terms of systems and subsystems. We must define our systems and subsystems in a way such that the calculator that is developed is practical yet as comprehensive as possible. Thus, it is important to identify each of the approaches used in the past or currently used as a first step in the process.

There are several comprehensive approaches that were identified. The building codes, HUD, NIST, and the Construction Specifications Institute have all made attempts to describe the house in terms of systems or subsystems. Likewise, some of the other literature further breaks down one or more systems into subsystems. Table 1 below summarizes the various definitions of the systems that make up a house. Note that these are primarily limited to the physical part of the house. Other parts of the “whole-house” system could include the influences of costs, management, or even the site development decisions. We have intentionally set limits defining the system as primarily related to the design, construction and performance of the home. The term “primarily” is used because it is not always feasible to make a clear distinction between the “physical” systems and the softer systems such as economics or costs. For example, the performance of the home from an energy efficiency standpoint is often measured by the homeowner in terms of utility costs.

Table 1

Source	System or Subsystem Definitions
International Residential Code, International Code Council, 2003	Describes the home systems two ways. The first way generally follows the order of construction, starting with the foundation and moving up through the floors, walls, roofs, and accessories like fireplaces. A Planning section at the front could be interpreted as a second approach to define the systems in a home. It is based around what could be loosely defined as performance issues for a few items such as termite protection or emergency egress.
CABO One and Two family Dwelling Code (later called the International One and Two family Dwelling Code), published every three years since the early 1970s	Same as the IRC above.
MasterFormat™, 2004 draft (Also published previously for last several decades on a periodic basis). Construction Specification Institute, 2004	Describes the items that go into a building (not limited to homes or any other type of building). It is a combination of performance related issues, materials, and equipment. Some systems are divided by trade, some by material. For example, Plumbing and HVAC are separate categories, while Wood, Plastics and Composites are another.
A better way to renovate, checklist for planning a healthy, energy efficient renovation. CMHC, 2003.	Describes the home in terms of location. Categories or systems include kitchen, bathroom, living, dining, bedrooms, basement, mechanical room, attic, and exterior.
Guide criteria for the design and evaluation of Operation Breakthrough Housing Systems, Volume IV- Single family detached, 1970, NIST for HUD	Breaks the home into 12 major systems: 1. structure, 2. walls and doors (inter-dwelling), 3. walls and doors (intra-dwelling), 4. floor-ceiling (interior), 5. walls, doors, and windows (exterior envelope), 6. roof-ceiling, 7. fixtures and hardware, 8. plumbing, 9. mechanical equipment and appliances, 10. power, electrical distribution, and communications, 11. lighting elements, 12. enclosed spaces.
Optimum Value Engineering Building System, 1973, Luebs for HUD	Describes the home as various systems and subsystems. Systems include: foundations, floors, exterior walls, roofs, interior partitions, and mechanical. Each of these are further divided into subsystems.
Minimum Property Standards for One and Two	Similar to the IRC in that the systems are defined as

Family Living Units, Federal Housing Administration, HUD, 1966 (other earlier and later versions also have been published)	the order of construction (Foundation up through roof), and some general performance "systems" are defined upfront. A mix of approaches.

Other literature describes parts of the home in terms of different systems. For example, several papers described the roof as a set of subsystems. For the most part, these partial definitions are not much different from several of the comprehensive approaches in the table above; they just cover a smaller part of the home.

Assessment of various ways to define the home as a system.

The systems can be divided into those that are based on some type of performance requirement or service need, those based on location, those based on trade delineations, those based on construction sequence or a combination of each. All of these have advantages and disadvantages in terms of building a calculator or tool to help improve housing. Mostly, the advantages and disadvantages come down to who ultimately will take the responsibility for designing and building the house as a system.

This requires an understanding of the way a house comes together. When we discuss the design process in the following paragraphs, keep in mind that this is representative of the way a large majority of homes are currently built. There are clearly other approaches and variations to the home building process depending on the size of the builder, regulatory requirements, and even regional preferences.

Design of a home is not usually the responsibility of a single person or even a dedicated team that closely coordinates all activities. There are typically many separate designers in a home. The HVAC contractor can design the ducts and equipment, an architect may do the floor plan and elevations, someone else may size the members for floor joists, a truss manufacturer may handle the roof framing, and the plumber "designs" the DWV and water supply system. Recently in some regions, the suppliers of floor systems such as I-joists have begun to design the entire framing package including support beams and posts. The builder may do some of these design tasks himself or, with a larger company, they may do some or all with in-house staff. The homeowner also frequently contributes to the design, especially with selection of finish materials or appliances. In any case, it is rare for there to be a single individual who has the overall design responsibility for a home. Any calculator that is intended to assist the industry needs to keep these issues in mind if it is to have any appreciable impact.

Given the above, it appears that none of the systems definitions found in the literature would be entirely sufficient by themselves, although some of the definitions do partially reflect some of the realities of the home building process. The ideal approach would be to define the home as if a single person was responsible for the entire design. This should be the long-term goal of the calculator. However, this requires radical change to the way homebuilders, trades, suppliers, and others in the industry currently operate. Another approach, which is not perfect by any means, is to define the systems according to who has individual responsibility for each and to find a way to get them the information on how their activities impact the other systems in the home. Even if they do not do the design, the work of each trade contractor is almost always designed separate from the rest of the systems in the home. For the majority of homes, this most likely means defining the systems and sub-systems for the whole-house calculator around the different trades who work on the home.

This approach should not suggest that the current fragmented approach to the design of homes is optimal. Rather, it is the starting point to get the separate system designers working together so that more and more of the systems and sub-systems are integrated, especially the systems where known, significant interactions exist. On the other hand, the calculator could be structured in a way that allows someone who is willing to take on the role of master designer to do so.

The approach of focusing only on the most important, documented systems interactions may not be viewed favorably by the advocates of whole-house design because it does not address every system and subsystem. However, it does provide the opportunity to begin the process of integrating the work of a subset of trades or activities by focusing on the handful of interactions that are meaningful. Thus, larger parts of the home will begin to be designed in an integrated fashion without expecting immediate, radical change to the way industry works throughout the entire supply chain.

Systems definitions based on activities with distinct designers would include at least the following systems or subsystems. For this exercise, we use the term “designer” loosely. In some cases there may be no formal design but someone still has the responsibility for determining how the system will be built, even if it is on the fly.

- Excavation
- Footings
- Foundation walls
- Foundation (concrete) flatwork
- Plumbing
- Electrical (wiring but not selection of lighting)
- Communications (IT, security, etc.)
- Lighting
- HVAC
- Conventional framing, windows and doors (including weather protection)
- Engineered framing (I-joists and trusses)
- Thermal envelope (Insulation/air sealing)
- Housewrap (may be combined with siding in some markets)
- Siding (Brick, vinyl, fiber cement, EIFS, wood, etc.)
- Drywall
- Paint
- Cabinets
- Interior trim
- Flooring

- Roofing
- Specialties (Fireplace, deck, doorbells, garage door, misc. trim)
- Grading
- Exterior flatwork (driveway, sidewalks)
- Stand-alone appliances and light fixtures
- Floorplan/elevations

Most of these systems are the responsibility of traditionally-defined trade contractors, suppliers, or the builder (or his representative). Some activities such as floorplan/elevations are not usually defined as a trade, but they are a separate activity performed by someone distinct from other trade activities. In many cases, it may be necessary to define the responsible party as the builder, designer, or consumer, or a combination of these groups.

The known interactions described later in Task 8 should be addressed in light of the system definitions. In other words, the calculator should specify the trades or activities that are involved in each system interaction so that specific responsibility can be assigned to the right parties. For example, designers on the floorplan/elevation activities should be able to show how their design addresses rainwater shedding through roof overhangs, gutters, downspouts, and grading.

Task 7. Review Past 'Whole House' Initiatives and Calculations

The primary objective of this task is to identify and review past attempts to coordinate 'whole house' systems analysis.

The terms "systems approach," "systems design," "systems thinking," "whole house design," whole building," and similar phrases have been widely adopted in the trade literature, by building-related associations, and by the agencies that fund housing research. The terms appear so often that shifting through the literature to find relevant items is a time-consuming task. Many of the articles discuss the systems approach or describe builders who claim to use it, but there are few documented examples with enough detail to support the claims. On the other hand, it appears from the trade press that there is a dedicated group of builders throughout the United States who claim to follow this approach. The literature that discusses their experiences is too sparse on details to determine exactly what they mean by a systems or whole-house approach. Most articles, especially in the trade press (see attached literature reviews), basically state that they consider the whole house and interactions between different parts of the home. How this is accomplished is usually left to the readers to determine on their own. These builders represent an opportunity to document whole house approaches but it will require extensive effort to do so.

The literature from the government agencies does provide some better-documented examples of past attempts at whole house or systems approaches. These are described in the following sections. More detailed descriptions are provided in the attachments. (The DoE Building America program results are not yet included as these are being addressed as an early Phase 2 task).

1. R-2000.

This program is a partnership between Natural Resources Canada (NRC) and the Canadian Home Builders Association. According to their website:

> "It began in the mid-1970s with a research project in the Prairies to develop ways of building homes that were comfortable and healthy to live in during the frigid winters, but used much less energy than conventional homes. These forerunners of R-2000 were modest-looking homes, with thick walls and small windows—a far cry from today's bright and sunny homes. The research resulted in the "house as a system" concept—a major evolution in building science. "House as a system" thinking recognizes that the flow of air, heat and moisture within a home is affected by the interaction of all the components, i.e., everything works together. If you make changes in one area, it will affect other areas—a simple concept that has profoundly changed the way all homes today are built."

The program has evolved into a certification program with rigid standards for all participating homes.

One of the difficulties in trying to document the R-2000 results is that the program evolved over time. Another is that the program draws on research results from other Canadian programs. Thus, there is no central depository within the program where one can look at all the interactions between the systems in the home, nor is there a single report that addresses the R-2000 whole-house approach. This should not imply that they operated in the dark. In fact, the Canadian literature (see attached review) supports many of the techniques (standards) in the R-2000 program, although it is drawn from research documents compiled over decades by CHMC and IRC-Canada.

Another way to look at the success of the program is by the number of homes built. There does not appear to be a firm handle on the number of R-2000 homes. Their R-2000 site states that there have been "thousands" built to date.

2. Canada Advanced Houses Program

This is a current program supported by the Natural Resources Canada. It is co-sponsored by the Canadian Home Builders Association. Like the R-2000 program, the focus is on energy and comfort issues, although a systems approach is claimed to be used. The NRC site defines the program as follows:

> "Advanced Houses are team efforts involving a broad range of the construction industry, including builders, architects and designers, engineers, manufacturers, researchers, utilities, and local home builders' associations as well as local and provincial governments. Advanced Houses are challenging Canada's home building industry to look to the future by developing and testing innovative methods of reducing energy consumption, providing a better indoor climate, and reducing the impact of houses on the environment. The results will be used to asses the commercial potential for new technologies and will form the basis for upgrading the R-2000™ standard, ensuring that R-2000™ homes remain at the forefront of housing technology."

There are ten homes in the program to date, scattered across Canada. Although the intent is to take R-2000 to the next level, the technologies themselves are broader than energy. They include everything from innovative septic systems to innovative wall materials. Thus, they may not offer as much to the whole-house approach as homes built of conventional materials like those in the R-2000 program.

3. Operation Breakthrough

One of this program's goals was to apply a whole-house approach to factory-built homes. It was successful in getting a series of demonstration housing developments built in the 1970s, but did little to increase the adoption of industrialized housing in the broader market. Almost all of the housing systems were dropped by the manufacturers before commercialization. However, there were some concepts that came out of Operation Breakthrough that continue to impact site built housing. These include results from work conducted by NIST and NAHB Research Foundation as described in the attached review of the program.

NIST developed the performance requirements for single family homes under Breakthrough. In a sense, they used a whole-house approach to these standards by looking at the various interactions between systems and subsystems.

NAHB Research Foundation developed the OVE (Optimum Value Engineered) approach. This is perhaps the best documented example of looking at the entire house and integrating the various systems together into a whole-house concept. Although the emphasis was on cost reduction in every system, most of the efficiencies were found in the design of the structure and items that overlapped the framing such as windows.

Many of the performance requirements in the NIST performance standards have found there way into the HUD Minimum Property Standards and the current International Residential Code (IRC). Parts of the OVE approach are also in the IRC and the approach has been embraced by the DOE Building America program and other energy efficiency programs that are based on systems design.

4. Energy Efficient House (EER I and II)

EER was one of the two significant HUD research programs initiated in the 1970s and 1980s after the completion of Operation Breakthrough. The other program was the Joint Venture for Affordable Housing, which had more of an emphasis on land development and planning issues than on the house itself.

EERs objectives were initially to find out how much energy could be saved in a home using off the shelf products and techniques. It addressed the cost and savings of various techniques, and their predicted and monitored performance. Subsequent to the first EER house, an EER-2 home was built. EER-2 was designed to explore more advanced measures that might become practical in the next five to 10 years.

Although not proclaimed as a whole-house effort at the time, in many ways the EER homes were some of the first where each system was examined to optimize it and then to integrate it with the other systems. Only a few homes were built under the program. The plans continued to be one of NAHB Research Center's best selling publications for over 15 years after the test homes were built, although there was no effort to track the actual number of homes built in the marketplace. Many of the techniques used in the homes for energy efficiency have become accepted practice in today's market.

5. Partnership for Advancing Technology in Housing (PATH)

PATH has been ongoing for about the past six years. It includes a wide range of research and dissemination activities designed to increase the value and affordability of homes. Only one specific project to date could be classified as embracing a whole-house approach - the Marketable, Affordable, Durable, Entry-level (MADE) home. The concept was to fully integrate the different systems in four homes to strike a balance between first cost, operating cost, and marketability. The project was supported by laboratory and field tests and incorporated many well known systems interactions including those between the ducts, envelope, architectural design features, HVAC equipment, windows and even accessibility. This project was different than many of the other "systems designed" homes in that it defined the system to include the interaction with the surrounding neighborhood, marketability issues, and affordability. The demonstration portion of the project was completed in late 2002. It is too early to tell what, if any, impact the MADE homes will have on the industry.

6. Lawrence Berkeley National Laboratory (LBNL) Case Study Field Evaluation of a Systems Approach to retrofitting a Residential HVAC System.

This is a series of case studies published in 2003 of eight homes where the systems approach was applied. Various systems and subsystems were assessed and integrated into a final design for rehab of the HVAC system. The program showed how various parts of the home need to be examined in order to optimize the overall performance of homes under renovation. The project was a real world application in that the researchers provided support to the owners or contractors but did not dictate which designs were to be used. Rather, the owners and contractors included items that made financial and practical sense.

Task 8. Review of Sub-Optimization Examples

The objective of this task is to identify interactions between the different systems and sub-systems in a home. These include where one system's performance can lead to unexpected decreases or increases in others and the core technical issues involved in these cases. Table 2 summarizes the results of the literature analysis. More details on specific references in the table are provided in the attachments.

Table 2

Item	Systems Effects or Benefits	Specific Actions	Systems or Subsystems Affected	Reference Documents
Planned or Engineered duct system and HVAC equipment sizing	• Downsizing HVAC equipment based on lower duct losses and improved envelope • Increased comfort due to better humidity control • Reduced energy losses	• Size ducts and equipment by design, not by rules of thumb, • Locate ducts to reduce exposure/thermal losses, • Minimize duct runs • Use higher performance windows • Consider impact of duct location on appearance or other functions of space	Ducts, framing, HVAC, Thermal Envelope, windows/doors, floorplan/elevations	L1, L2, L3, L4, T11, T12, T16, 05, P1, P5, P7, 82, 85, 87
Backdrafting	Tight homes interact with combustion equipment, fireplace, exhaust or air-moving equipment to depressurize house or rooms, cause CO and other combustion products to spill into living space	• Avoid cool chimneys • Avoid “competing” chimneys • Consider house tightness effect on combustion appliances and fireplaces • Reduce impact of exhaust fans and exhaust-only ventilation equipment • Use sealed/power vented equipment	HVAC, Appliances, Fireplace, Thermal envelope, Plumbing (fans)	T1, T2, T3, T5, T11, EP2, C11, C18, 44, 101
Condensation	Tight homes without adequate ventilation or high indoor humidity can result in condensation, mold, mildew on colder surfaces such as windows and walls.	• Provide adequate ventilation • Control indoor humidity levels • Minimize cold spots on walls • Upgrade windows	HVAC, thermal envelope, windows, appliances	T1, E2, E3, P5, 102, 103, 104, 106, 108
Solar (passive) design	Window and house orientation relative to sun and roof overhangs influence energy use	• Orient windows to south • Minimize window area on other orientations • Use roof overhangs to provide solar shading	Floorplans/elevations, windows/doors, framing	T6, E1, E2, E3, 64, 65, 66
Floorplan design	Corners and exterior walls influence energy use	• Minimize outside corners and wall length and height	Framing, floorplans/elevations	T6, E1, E2, E3, 21
Advanced or OVE framing	Type and spacing of framing members often dictates how much room is available for insulation. Use of thermal (foam) sheathing can degrade structural performance.	• Optimize framing to reduce number of members and increase spacing • Check shear resistance of walls when not sheathed with OSB or plywood	Framing, thermal envelope	T7, T12, T16, E1, E2, E3, P9

Item	Systems Effects or Benefits	Specific Actions	Systems or Subsystems Affected	Reference Documents
Roof ice formation and ice dams	Attic ventilation, supply ducts, roof overhangs, and gutters are all factors that can cause ice dams or eave icing.	• Design roof with overhangs and gutters • Insulate or remove ducts from attics • Ventilate attics in cold climates	Framing, HVAC, floorplan/elevations	T10, F1, P6
Reflective roof coverings	Roof color/material influences roof temperatures and energy use	• Select roofs that improve cooling efficiency (light colors on metal or tile)	Roofing, HVAC equipment	T13, F1, F3, N4, C21, 31, 32, 33, 34, 35
Landscaping	Shading from trees can reduce heat gains, impact HVAC sizing	• Size systems based on shading benefits	Landscaping, windows, HVAC	T15, E1, E2, E3
Appliance and lighting selection	Both impact the loads that determine HVAC equipment sizing	• Consider lighting and appliance efficiencies in HVAC sizing	Lighting, appliances, HVAC	T16, E1, E2, E3
Roof truss and floor designs	Conditions over end wall should allow for attic insulation without compression. Open floor plans in increasingly larger homes and newer structural products can create floor vibration problems.	• Design truss conditions based on height of insulation required. • Design floors to limit vibration (beyond current deflection criteria), especially in longer spans and with engineered products.	Framing, engineered framing, thermal envelope, floorplan/elevations	E1, E2, E3, C19
Electrical receptacles	Placement and type of electrical boxes influence air leakage into cavity, reducing energy efficiency and setting up conditions for condensation in cavities	• Eliminate or minimize wiring in exterior walls (as much as code permits) • Use surface mounted systems	Framing, thermal envelope, electrical	E2, 91, 92, 93
Window operation	Malfunctioning windows often traced to header deflection	• Size headers specifically for loads • Install without rigid connection or shims between windows and headers	Framing, windows	O1, C12
Cladding thermal distortions	Vinyl and aluminum siding will appear wavy if not attached correctly	• Hang siding, don't nail tight to frame • Leave room for expansion	Framing, siding, floorplan/elevations	O1
Wall opening leakage	Proper flashing of doors and windows will help eliminate moisture and rotting problems.	• Develop an integrated water management plan to address flashing, drainage plain, and/or roof overhangs.	Framing, windows/doors, siding, housewrap	O2, P4, C4, C8, C12, 76, 101

Item	Systems Effects or Benefits	Specific Actions	Systems or Subsystems Affected	Reference Documents
Large holes or notches in framing	Plumbing, flues, ducts can't generally go through framing members without degrading structural capabilities	• Plan location of utility systems and framing members	Electrical, plumbing, HVAC, framing, Engineered framing	O5, 17
Drywall cracks or pops	Installation practices, design and selection of structural materials can contribute to drywall finish imperfections	• Design trusses and connections to eliminate truss uplift (partition separation) • Provide specific details for drywall installation at openings • Avoid wet lumber • Avoid wide changes in attic and interior humidity levels	Framing, drywall, engineered framing, thermal envelope, HVAC	O5
Attic and cathedral ceiling moisture	Ventilation, tight ceiling construction, outdoor conditions, and indoor humidity levels all influence moisture in ceiling and attic spaces. Ventilation to outdoors may be undesirable in wet climates	• Conduct a moisture assessment or design that considers factors other than ventilation as primary methods for moisture control in moist climates	Thermal envelope, framing	F1, F3, P5, P6, P7, 40, 75, 139, 140, 78
Impermeable exterior wall barriers	A vapor barrier on the outside of a wall can trap moisture in a colder climate, rotting plywood and studs. The same effect may occur with a vapor barrier in hot humid climates.	• Do not use low permeable materials on exterior, including foam insulation, unless alternative methods are used to address potential moisture.	Thermal envelope, framing	F2, P5, N3, C6, 36, 37
Rain susceptible architectural details	Roof overhangs, cantilevered balconies, bay windows, and corners all make the envelope more susceptible to water penetration.	• Minimize architectural details or develop specific details for each type. • Consider the use of roof overhangs as a safety factor over wall openings.	Floorplan/elevations, framing, decks, windows/doors, siding	F4, P2. P4, C4, C8
Drainage at foundation	Foundation cracks and basement, crawlspace, and slab water problems are more often related to exterior grade than to interior moisture sources, groundwater, or to poor structural design.	• Provide positive drainage from roof and ground away from foundation including gutters and downspouts or roof overhangs in combination with positive grading		P2, P5, C1, C2, C13, C14, C20
Crawlspace moisture management	Moisture problems can be largely avoided by providing air-permeable barriers	Consider the use of air distribution systems in reducing moisture levels in crawl spaces	Thermal envelope, framing, foundation	128, 105, 108
Item	Systems Effects or	Specific Actions	Systems or	Reference

	Benefits		**Subsystems Affected**	**Documents**
Ventilation	Ventilation provides acceptable indoor air quality	• Bring fresh air into the general environment • Dilute pollutants that cannot be controlled at the source	Thermal envelope, HVAC	6, 90, 128, 130, 131, 134, 77, 79, 83, 89
Communication	In-home communication and entertainment needs can be achieved through control and management systems that distribute voice, video and data technologies throughout the house	• Design the different areas in a house where automation is desired • A controller box can control up to six different zones	Communication, electrical, framing, drywall	97, 98, 99, 133
Indoor Air Quality	Cracks and heating/cooling ducts form a conduit for pollutants entering the home	• Consider impact of design on radon penetration through heating registers	Framing, foundation, HVAC	109, 110, 111, 112, 113, 114, 115, 127, 128, 137, 138, 142
Water Conservation	Water can be conserved through the practice of management, design, installation and use.	• Consider demand water heaters with a parallel piping distribution system	Plumbing, floorplan	94, 96
Whole House System	Detect housing problems and develop a system approach to search for improvement	• Design a housing matrix to identify problems and to assess improvements • Choosing an appropriate construction system will increase thermal comfort, lower construction costs and reduce the environmental impact	All systems	119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 131, 141, 142, 19, 20, 29, 48, 80, 84, 142
Green building	Our resources must be utilized efficiently to create healthier homes	• Coatings on glass can reduce energy consumption • Waste hot water can be recovered and reused • Select building materials with insulation as an important factor	HVAC, envelope, plumbing,	123, 135, 15, 18, 28, 29, 52, 53, 56, 57, 58, 59, 63, 45, 95
Heating and cooling systems	The interaction between the building and the heating installation must be optimized to avoid heat and cooling loss	• Efficient heating and cooling systems must be used, windows and doors need to be detailed, ducts must be sized and walls must be sealed	HVAC, insulation, housewrap, framing	3, 5, 73, 74, 78, 80, 81, 84, 86, 88, 129, 132, 136
Item	**Systems Effects or Benefits**	**Specific Actions**	**Systems or Subsystems**	**Reference Documents**

			Affected	
Concrete floors and walls	Concrete is ideally suited to residential construction where wind storm and energy conservation are important design criteria	• Provide fire safety and thermal storage properties	insulation, framing, HVAC	7,8, 9
Wood	The performance of light-frame wood assemblies is affected by load-sharing, partial composite action of members and sheathing, and connection behavior	• The presence of elastomeric construction adhesives between joists and sheathing help reduce floor deflections • Assess sheathing and attachment details for structural adequacy and thermal envelope issues	Framing, thermal envelope	14, 16, 27, 62
Ceiling	Heat transport in ceiling insulation is assumed to be transferred by three mechanisms	• The addition of a vapor barrier at the substrate can reduce the total heat transfer (by reducing air leakage)	HVAC, envelope	43
Energy efficiency and conservation	Energy performance considerations suggest minimizing window areas and insulating walls to prevent heating and cooling loss	• Internet-based communication techniques can be used to monitor building energy end-use	HVAC, thermal envelope, communications	50, 51, 52, 53, 54, 55, 57, 58, 59, 60, 61, 63, 45, 46, 47, 48, 49, 67, 68, 69, 70, 71, 78, 92, 96
Comfort	Human comfort is dependent on temperature, humidity, air velocity and activity levels	• An integrated comfort sensing system can provide an effective means of measuring comfort levels	HVAC, thermal envelope, communications	116, 118, 72, 86
Shingle life	High temperatures can reduce shingle life	• Consider selection of tile or metal roof if eliminating attic ventilation	Roofing, framing	P6

Item	Systems Effects or Benefits	Specific Actions	Systems or Subsystems Affected	Reference Documents
Roof type	Gable roofs are more susceptible to damage from high winds than hip roofs. Flat roofs are more susceptible to roof leaks resulting from condensation.	• Consider hip roof in high wind areas • Develop specific truss and sheathing attachments to specifically resist high winds, especially for gable roofs and overhangs. • Evaluate the condensation potential for flat roofs in colder climates.	Framing, elevations, thermal envelope	P8, C17, 24, 25, 26
Carpet soiling	Leaky return ducts and wall leakage can cause soiling of carpets in otherwise tight homes	• Build a tight building shell throughout • Avoid returns in framing spaces • Build tight ducts, especially returns • Avoid light color carpets	Framing, thermal envelope, HVAC	C3
Wall openings in seismic zones	Window and door placement can create soft stories that can perform poorly in seismic events	• Consider the shear wall capacity when designing elevations	Framing, elevations, windows/doors	C5, T6
Sound transmission	Electric boxes and stud spacing can impact sound performance in homes	• Consider wider spacing of studs if improved STC ratings are desired • Space electrical boxes to avoid back-to-back installation in attached homes	Framing, electrical	C9, C10
Foundation type	Basements are most susceptible to moisture problems in high ground water areas and with poorly drained soils	• Consider a crawlspace when poorly draining soils or groundwater are present	Foundation, floorplan/elevations	C14, 38, 39, 22, 23
Ghosting	Dirt patterns on walls and ceilings can occur if thermal insulation is not uniform, creating colder spots where particles are drawn.	• Provide QA for insulation. • Consider the impact of framing members in forming cold bridges in colder climates.	Framing, thermal envelope	C22, 1

Note: Codes in the reference document column are defined in the attachment listing below.

Attached Literature Searches:

Attachment A

- Canadian Government Literature (C)
- Energy Efficient Residence Literature (E)
- Environmental Protection Agency Literature (EP)
- Forest Products Laboratory Literature (F)
- Lawrence Berkeley National Lab Literature (L)
- National Institute for Standards & Technology Literature (N)
- Operation Breakthrough Literature (O)
- Partnership for Advancing Technology in Housing Literature (P)
- Trade Press Literature (T)

Attachment B

- Technical / Scientific search (Number)

Each relevant document in the trade press and government programs is identified by a letter as shown in parenthesis in the list above to connect it with an agency or the trade press, followed by a numeric code for each document in each attachment. The literature from the technical/scientific documents is identified by numeral only.

Attachment A – Government and Trade Press Literature

Canadian Government Literature

The Canadians have done perhaps the best job of documenting their work and making it accessible to the public. Almost all of their agencies that conduct housing research rely extensively on the web to disseminate their findings. Even in cases where full text of documents is not on the web, they have gone to great lengths to provide summaries of their work.

This part of the literature search and review focused on the following sources:

1. Canadian Mortgage and Housing Corporation (CMHC)
2. Institute for research in Construction (IRC), part of the National Research Council Canada.

C1. Project Name. **Crawl space ventilation and moisture control in British Columbia houses.** CMHC R&D Technical Series 90-231, Don Fugler, 1991.

Description/Scope: 10 houses built within 8 years of the project were surveyed and tested to evaluate moisture levels, air tightness, and soil conditions.

How does this relate to systems approach: The researchers identified and confirmed a relationship between the soil and the moisture in the crawlspace, and between the drainage around the home and moisture problems in the home. Houses on well drained soils had no crawl space moisture problems even if they did not have vents. A ground cover is suggested to mitigate groundwater wicking.

Data discussion: The findings are based on visual observations before and after corrective actions. The authors note that the sample of homes is not random.

C2. Project name: **Before you start renovating your basement – moisture problems.** About your house fact sheet, CE28c. CHMC, no date given.

Description/Scope: Consumer-oriented fact sheet based on knowledge of CHMC experts. The emphasis is on how to avoid moisture problems when finishing a basement.

How does this relate to systems approach: The fact sheet discuss the house as a system. It identifies different activities or changes and how they impact other parts of the home's performance. Perhaps the most useful interactions are between the exterior drainage system, or lack of one, and the moisture in a basement that will impact materials and IAQ when a basement if finished.

Data discussion: No real data. Just expert opinion, but from a reputable source.

C3. Project Name: **Carpet streaking.** About your house series CE14, CHMC, no date given.

Description/Scope: Describes carpet streaking and ways to prevent it in homes.

How does this relate to systems approach: The fact sheet relates air tightness to the sooting or streaking that can occur around the perimeter of carpets. Sources such as candle burning are also cited as contributing causes. Specific practices related to the design that should be avoided include use of return ducts that leak or that use the framing spaces as the return, since these can cause localized depressurization and draw particles and air through the carpet. Conversely, a tight building shell, especially at the wall-floor joint, is encouraged to reduce air leakage pathways.

Data discussion: No real data. Just expert opinion, but from a reputable source.

C4. Project name: Wall moisture problems in Alberta dwellings, Research highlights technical series 00-12, CHMC, December 2000

Description/Scope: Data was collected from 41 houses and 9 multi-unit buildings to assess the causes of moisture problems.

How does this relate to systems approach: The study confirms that poor detailing at windows, doors, and decks was a contributing factor in 91% of the homes with moisture problems. They also relate the interaction between moisture problems and some aesthetic and construction details such as vertical transitions, soffits that slope down to a wall, rail attachments, scuppers, and parapets.

Data discussion: Relationships that are defined are general. However, there were a large number of homes in the study.

C5. Project Name: Ensuring good seismic performance with platform frame wood construction. Construction technology Update No. 45, IRC, Rainer and Karacabeyli, 2000.

Description/Scope: Provides a review of earthquake related performance issues with wood frame construction and solutions to past problems.

How does this relate to systems approach: This review relates the interaction between window and door selection and placement to shear resistance in buildings under seismic loads. It cites the poor performance of soft stories in the Northridge earthquake as one example.

Data discussion: There is no new data, but the authors cite surveys conducted by others. The interactions between aesthetic issues like windows and structure are well documented in other literature.

C6. Project name: Low permeance materials in building envelopes. Kumaran and Haysom, IRC, Construction Technology Update No. 41, 2000.

Description/Scope: Article describes a project to model moisture and condensation potential in walls of various configurations. The main focus was on the impact of placing insulation on the exterior of the wall in cold climates. A ratio of interior to exterior R-value is presented to prevent condensation when a low-permeance material is used on the exterior of a wall.

How does this relate to systems approach: This article shows the interaction between location of insulation in walls and the potential for condensation in the wall cavity. This could become increasingly important in the US as more homes are built with foam insulation on the exterior to meet energy codes.

Data discussion: Conclusions are based on modeled results.

C7. Project Name: Testing of fresh air mixing devices, R&D Highlights technical series 93-206, CHMC, 1993.

Description/Scope: Article describes a laboratory experiment to assess various methods to mix air being intentionally drawn into a home for ventilation purposes. Temperature measurements were conducted to determine the efficiency of each device at mixing the air.

How does this relate to systems approach: One conclusion of the authors is that introducing untempered cold air into an energy efficient duct system could lead to comfort problems and to corrosion or cracking problems in furnace heat exchangers. (With the increasing use of fresh air ducts to the return plenum, this may begin to cause problems in some furnaces in the future in the United States.) The authors cite the irony that poorly built, leaky ducts are better mixers and may have prevented cold pooling in the past that could occur with energy efficient duct systems.

Data discussion: Findings are based only on laboratory testing. The relationship between heat exchanger cracking is not established by the lab testing, but is theorized by the authors.

C8. Project name: Survey of building envelope failures in the coastal climate of British Columbia, CMHC, Research Highlights, Technical series 98-102, 1998

Description/Scope: This highlight describes sampling and evaluation of 37 problem homes and 9 control homes to assess moisture problems and causes.

How does this relate to systems approach: The results show that exterior water is the source that caused most moisture problems in the homes, not interior or construction sources. Interactions were identified between architectural features and moisture problems (leaks) including at doors, windows, decks, and penetrations of the walls. The authors also cite a relationship between lack of roof overhangs and wall envelope moisture problems.

Data discussion: Based on a relatively large sample for this type of work, although limited to one very wet climate.

C9. Project Name: Research project on the noise insulation provided by exterior walls in wood construction. Research Highlights technical Series 99-124, CMHC, no date but assume 1999 by the series number.

Description/Scope: Nine sound transmission loss tests were conducted on four exterior walls. Two with 2x4 and two with 2x6 walls, each at 24 and 16 inch spacing with various sheathing products.

How does this relate to systems approach: The project showed how the spacing of structural members and the selection of wall sheathing products can impact noise levels. The 24 oc spacing increased the STC by 6 points over 16 oc spacing. Likewise fiberboard covered walls had slightly better sound performance than OSB covered walls.

Data discussion: Data and conclusions are based on test results.

C10. Project name: Degradation of wood stud wall sound insulation by electrical outlets, CMHC Research Highlights Technical Series 96-229, 1999.

Description/Scope: 56 tests of wall assemblies were tested to ASTM E90 to investigate the impact of electrical boxes on sound transmission.

How does this relate to systems approach: The results show how the electrical system, including placement and type of electrical box, impact the sound performance of walls. Plastic boxes performed better than metal. To minimize reductions in sound performance, electrical boxes should not be placed back to back in wall assemblies.

Data discussion: Data and conclusions are based on tests conducted in accordance with a consensus standard.

C11. Project Name: Field tests of ventilation systems installed to meet the 1993 OBC and 1995 NBC, CMHC Research Highlights technical series 00-106. No date, but 2000 likely by series number.

Description/Scope: 49 homes across Canada were investigated to conduct field tests of various mechanical ventilation systems recognized by the National Building Code of Canada and the Ontario Building Code. Emphasis was placed on determining the extent to which depressurization could occur in the homes, leading to backdrafting.

How does this relate to systems approach: This shows the possible negative interaction (backdrafting) that can occur if a mechanical ventilation system is not properly designed in an energy efficient home. Measurements showed depressurization occurred less often than predicted, but it still occurred in a large majority of the homes.

Data discussion: Findings are supported by both modeling and field measurements.

C12. Project Name: Design of durable joints between windows and walls. CMHC Research Highlights technical series 03-107, July 2003

Description/Scope: Describes design approaches to maintain the integrity of the envelope to prevent air infiltration, rain seepage, deterioration of insulation and finishes, and mold prevention.

How does this relate to systems approach: Identifies relationships between window installation and performance of other systems. Perhaps most important are the impact of non-existent or poor flashing on moisture in the home and the impact of the installers improper use of shims at the top of the window resulting in the header loads above being transferred to the window, which then will not open properly if at all.

Data discussion: No data presented. More of a review of good practice based on work of others and expert opinion.

C13. Project Name: **Case study on basement renovations**, CMHC Research Highlights technical series 01-105

Description/Scope: Describes a study to identify the measures required to reduce humidity in basements. Ten homes were assessed and renovated. Moisture levels were observed and monitored before and after renovations were conducted.

How does this relate to systems approach: The findings relate the impact of the exterior water management systems to the interior performance of the homes. Major items include the impact of ground slope and eavesthroughs (gutters and downspouts) on basement moisture levels.

Data discussion: Small sample but monitoring data used to support conclusions. The performance of some of the mitigation methods could not be separated out from others so there is some assuming on the author's part that certain practices contributed to moisture prevention.

C14. Project Name: **A study of recurring mold problems on the Roseau River reserve, Manitoba**, CMHC Research Highlights technical series 99-101.

Description/Scope: Describes a study of mold problems in 114 flood damaged homes that continued to have problems well after the clean-up. Moisture levels were observed and monitored before and after renovations were conducted.

How does this relate to systems approach: The findings relate the impact of the exterior water management systems to the interior performance of the homes. Major items include the impact of ground slope and eavesthroughs (gutters and downspouts) on basement moisture levels. The authors also relate the selection of foundation type to moisture problems. They recommend crawlspaces in poorly drained soils with high water tables as opposed to basements.

Data discussion: Good size sample of homes (114). On-site data collection used to support findings.

C15. Project Name: **A better way to renovate, checklist for planning a healthy, energy-efficient renovation.** CMHC Web article at www.cmhc-schl.ga.ca/en/burema/repi/bewarehi/bewarehi_003.cfm , no date but downloaded December 2003.

Description/Scope: Describes a checklist for approaches and features to consider when planning a home energy retrofit.

How does this relate to systems approach: No interactions are identified, but the paper presents a list of systems (and subsystems) in a home as follows:

- Pre-renovation inspection
- Kitchen
- Bathroom
- Living, dining, and bedrooms
- Basement
- Mechanical room
- Attic
- Structure
- Exterior
- Landscaping

This list of systems represents one way to possibly organize the whole-house calculator.

Data discussion: No data or documentation, just a list of the systems in a home.

C16. Project Name: Effects of wood shrinkage in buildings, A.T. Hansen, CBD-224, IRC, February 1987

Description/Scope: This digest discusses the nature of wood shrinkage and its effect on the performance of certain building assemblies.

How does this relate to systems approach: The article cites the interaction between wood moisture levels and the appearance of interior finishes. It related changes in moisture, and use of wet lumber in particular, to drywall nail pops and truss uplift.

Data discussion: No new data, but supported by multiple well known reference documents including the USDA Wood Handbook

C17. Project Name: Moisture problems in houses, AT Hansen, CBD-231, IRC, May 1984

Description/Scope: Paper examines the causes of condensation problems in homes and ways of reducing or eliminating them.

How does this relate to systems approach: Article relates several systems and subsystems:

- Holes for electrical boxes in exterior walls that create leakage paths and contribute to condensation potential
- Exhaust ducts through concealed spaces can deposit moisture in unwanted locations
- Selection of roof type (flat roofs are more prone to serious roof leaks resulting from condensation).

Data discussion: No new data, but supported by multiple well known reference documents.

C18. Project Name: Airtight houses and carbon monoxide poisoning, CBD-222, F. Steel, IRC, March 1982.

Description/Scope: This digest reviews the impact of air exhaust systems on appliance vent performance relative to building pressures.

How does this relate to systems approach: Describes the conditions for potential backdrafting in tight homes including competition between appliance and fireplace chimneys. In a theoretical house, they author shows how a chimney can cause a 25 Pa draft, which would require replacement air of at least 170 l/s to prevent other chimneys from backdrafting.

Data discussion: Findings are based on a theoretical home, but one that is typical of Canadian homes in terms of air tightness and appliances. Conclusions are supported by calculation results.

C19. Project Name: Floor vibration, CBD-173, DE Allen and JH Rainer, IRC, September 1975.

Description/Scope: This digest discusses the nature of floor vibrations and how they relate to people and structural safety. It includes some guidelines for design.

How does this relate to systems approach: Indirectly relates the selection of floor materials and floor plans with longer spans to poor performance due to excessive vibration. They claim that the current deflection criteria of l/360 can account adequately for vibration but not so for longer spans.

Data discussion: Based on expert opinion and work at the Canadian Forest Products Lab.

C20. Project Name: Moisture and thermal considerations in basement walls, CBD-161, CR Crocker, IRC, 1974.

Description/Scope: Presents a review of performance issues in homes with particular emphasis on moisture and thermal performance in basements.

How does this relate to systems approach: Relates how exterior grading, gutters, downspouts, and other parts of the exterior drainage system can create moisture problems in basements if not designed and constructed properly.

Data discussion: Based on expert opinion and knowledge from other projects.

C21. Project Name: Thermal considerations in roof design, GK Garden, CBD-70, IRC, October 1965.

Description/Scope: Describes a wide variety of thermal issues including control of heat loss/gain.

How does this relate to systems approach: Identifies a relationship between the home's exterior appearance (roof color) and summer heat gain. Lighter colors reflect more solar radiation than dark colors.

Data discussion: Provides recommended values for solar absorption of different colors, but no references are provided.

C22. Project Name: Thermal insulation in dwellings, CBD-16, WH Ball, IRC, 1961

Description/Scope: Provides an overview of insulation practices and potential problems that insulation can create if not used properly.

How does this relate to systems approach: Identifies a relationship between non-uniform thermal protection and interior appearance. Specifically, the high variations in surface temperature can contribute to dust patterns, or ghosting, on walls and ceilings in homes.

Data discussion: Based on expert opinion and observations of IRC staff.

C23. Project Name: Condensation on inside window surfaces, CBD-4, AG Wilson, IRC, April 1960.

Description/Scope: Describes issues related to condensation on windows and more severe moisture problems.

How does this relate to systems approach: Relates heating register placement to window temperatures and thus condensation potential.

Data discussion: Based on expert opinion.

C24. Project Name: Moisture Management for Exterior Walls (MEWS)

This project is funded by the Institute for Research in Construction of the National Research Council Canada. The project web site provides the following overview:

> "The objective of this project is to develop guidelines for moisture management strategies for wall systems to meet user requirements of long-term performance and durability for the wide range of climate zones across North America. This project is about defining the ability of certain wall systems to manage moisture sources, including construction moisture, humid indoor and outdoor air, precipitation, and indoor human activities. Moisture may enter in many ways, including vapor diffusion, air movement, rain penetration, and seepage. The envelope design strategy must address all such processes, and must control moisture accumulation throughout the annual climatic cycle, over many years of service life. The focus will be on wood-frame buildings of 4 storeys or less, exposed to a range of outdoor climates found in North America (heating, cooling and mixed) starting with the warm and humid climate. Rain penetration control strategies will be based on the rain-screen principle. The research approach is three fold: field characterization of assemblies, laboratory experimentation on materials and components and mathematical modeling for prediction of long-term performance under many sets of conditions."

To date, there have been a series of task reports on this project. Perhaps the document that best describes the project results in a succinct manner is as described below:

An integrated methodology to develop moisture management strategies for exterior walls,

M.K. Kumaran et. al. Presented at the 9th Canadian Conference on Building Science and Technology, Vancouver, February 27-28, 2003.

Description: Describes the MEWS consortium project's development of an integrated methodology to assess long-term performance of exterior walls relative to moisture. The program included a review of field studies, measurements of hygrothermal properties of materials, definition of loads, investigation of damage functions, wind-driven rain experiments, and modeling using hygIRC, an advanced hygrothermal model. The study includes application to several types of wall claddings including concrete, stucco, EIFS, and wood/vinyl siding.

How does this relate to systems thinking? Shows the need to consider many factors in the design of a wall including material properties, climate, protection from surrounding projections, and deficiencies that can let in bulk water and heavily influence the moisture load on a wall. Practical strategies to improve moisture management include:

- Use of drainage planes behind the cladding
- Reduction of deficiencies that result in water entry
- Sheltering of the wall to reduce moisture exposure
- Materials with better drying characteristics

Data discussion: The findings are supported by a number of well-documented research reports and references, and by the parametric modeling in the study. One could argue that there are parts of the program that use unrealistic scenarios such as the wall experiments for wind-driven rain or even arbitrary "deficiencies" in the wall sections. However, even if these are extreme or arbitrary conditions, the relative differences in the wall systems' performance reveal some systems interactions and suggest some practical recommendation to control moisture that have been supported in many other studies.

Other Canadian documents reviewed but redundant, not deemed relevant or not enough detail.

Canadian Building Digest:

CBD-245. Mechanical Ventilation and Air Pressure in Houses, C.Y. Shaw, May 1987.

CBD-229. Thermographic Identification of Building Enclosure Effects and Deficiencies, G.A. Chown and K.N. Burn, December 1983.

CBD-232. Vibrations in Buildings, J.H. Rainer, May 1984.

CBD-236. Introduction to Building Acoustics, A.C.C. Warnock, February 1985.

CBD-207. Hazards from Products of Combustion and Oxygen Depletion in Occupied Spaces, A.D. Kent, October 1979.

CBD-199. Air Ions and Human Comfort. C.Y. Shaw and G.T. Tamura, October 1978.

CBD-182. Frost Action and Foundations, K.N. Burn, November 1976.

CBD-180. Ground Temperatures, G.P. Williams and L.W. Gold, July 1976.

CBD-178. Fire and Plastic Foam Insulation Material, G.W. Shorter and J.H. McGuire, June 1976.

CBD-147. Structural Safety, D.E. Allen, March 1972.

CBD-130. Wetting and Drying of Porous Materials, P.J. Sereda and R.F. Feldman, October 1970.

CBD-171. Inaccuracies in Construction, J.K. Latta, April 1975.

CBD-142. Space Heating and Energy Conservation, D.G. Stephenson, October 1971.

CBD-126. Influence of Orientation on Exterior Cladding, C.R. Crocker, June 1970.

CBD-125. Cladding Problems Due to Frame Movements, W.G. Plewes, May 1970.

CBD-112. Designing Wood Roofs to Prevent Decay, M.C. Baker, April 1969.

CBD-115. Performance on Building Materials, P.J. Sereda, July 1969.

CBD-111. Decay of Wood, M.C. Baker, March 1969.

CBD-110. Ventilation and Air Quality, A.G. Wilson, February 1969.

CBD-107. Stack Effect and Building Design, A.G. Wilson and G.T. Tamura, November 1968.

CBD-104. Stack Effect in Buildings, A.G. Wilson and G.T. Tamura, August 1968.

CBD-106. The Basic Air-Conditioning Problem, N.B. Hutcheon, October 1968.

CBD-90. Coatings for Interior Walls, H.E. Ashton, June 1967.

CBD-86. Some Implications of the Properties of Wood, N.B. Hutcheon and J.H. Jenkins, February 1967.

CBD-68. Wind Pressures and Suctions on Roofs, W.A. Dalgliesh and W.R. Schriever, August 1965.

CBD-56. Thermal and Moisture Deformations in Building Materials, M.C. Baker, August 1964.

CBD-54.Deflections of Horizontal Structural Members, W.G. Plewes and G.K. Garden, June 1964.

CBD-48. Requirements for Exterior Walls, N.B. Hutcheon, December 1963.

CBD-41. Sound and People, T.D. Northwood, May 1963.

CBD-34. Wind Pressures on Buildings, W.A. Dalgliesh and W.R. Schriever, October 1962, revised May 1968.

CBD-30. Water and Building Materials, J.K. Latta, June 1962.

CBD-28. Wind on Buildings, W.A. Dalgliesh and D.W. Boyd, April 1962.

CBD-26. Ground Freezing and Frost Heaving, E. Penner, February 1962.

CBD-23. Air Leakage in Buildings, A.G. Wilson, November 1961.

CBD-20. Corrosion in Buildings. P.J. Sereda, August 1961.

CBD-14. Weather and Building, D.W. Boyd, February 1961.

CBD-13. House Basements, C.R. Crocker, January 1961, amended February 1974.

CBD-3. Soil and Buildings, R.F. Legget, March 1960.

CBD-1. Humidity in Canadian Buildings, N.B. Hutcheon, January 1960.

CBD-9. Vapour Barriers in Home Construction, G.O. Handegord, September 1960.

CBD-12. House Foundations, C.B. Crawford, December 1960.

CBD-40. Rain Penetration and its Control, G.K. Garden, April 1963.

CBD-42. Humidified Buildings, N.B. Hutcheon, June 1963.

CBD-44. Thermal Bridges in Buildings, W.P. Brown and A.G. Wilson, August 1963.

CBD-72. Control of Air Leakage is Important, G.K. Garden, December 1965.

CBD-73. Moisture Considerations in Roof Designs, G.O. Handegord, January 1966.

CBD-156. Drainage Around Buildings, G.P. Williams, 1973.

CMHC-SCHL:

Wet-Sprayed Cellulose Insulation in Wood-Frame Construction, Norbert Koeck, 1990.

Ventilation Systems for New and Existing Houses with Electric Baseboard Heating, Duncan Hill, 1996.

Thermostat Settings in Houses with In-Floor Heating, Jennifer Foote, 2001.

Thermal Testing of Wall Sections in the Northwest Territories, Robin Sinha, 1990.

The Zero-Cavity and DPV Wall Project, Jacques Rousseau, 1996.

Testing Rainscreen Wall and Window Systems: The Cavity Excitation Method, Jacques Rousseau, 1996.

Testing of Air Barrier Systems for Wood Frame Walls, Jacques Rousseau, 1998.

Residential Water Conservation: A Review of Products, Processes and Practices, Alvin J. Houston, 1997.

Research Project on the Noise Produced by DWV Pipes Made of Cast Iron, PVC and ABS, Duncan Hill, 2002.

Quality by Design: A Quality Assurance Protocol for Wood-Frame Building Envelopes in British Columbia, Jacques Rousseau, 1999.

Performance of Simplified Ventilation Systems, Duncan Hill, 1995.

Noise Isolation Provided by Gypsum Board Partitions, Jacques Rousseau, 2002.

Investigation of the Performance of Gypsum Sheathing, Jacques Rousseau, 1998.

Crawl Space Ventilation and Moisture Control in British Columbia Houses, Don Fugler, 1990.

Investigation of Black Soot Staining in Houses, Don Fugler, 2000.

Investigating, Diagnosing and Treating Your Damp Basement, Don Fugler, 1992.

Incompatible Building Materials, Darrel R. Smith, May 2003.

Flanking Sound Transmission in Wood Framed Construction, Jacques Rousseau, 1996.

Field Survey of Heat Recovery Ventilation Systems, Duncan Hill, 1996.

Exterior Insulation and Finish Systems (EIFS): Problems, Causes and Solutions, Peter Russell, 2000.

Evaluation of Physical Adaptations and Home Automation Features in Four Housing Units Located in Ville Saint-Laurent, Quebec, Sandra Marshall, 1997.

Energy Efficient Windows, Lighting & Human Health, Virginia Salares, 1996.

Energy Efficiency Technology Impacts Appliances, Duncan Hill, 1995.

Effectiveness of a Hard-Connected Duct as a Source of Ventilation and Make-Up Air, Robin Sinha, 1991.

EASE Demonstration Project (APCHQ's Advanced House), Jacques Rousseau, 1998.

Domestic Hot Water Tanks as a Space Heating Appliance, Robin Sinha, 1990.

Defining the Convective Driving Force for Soil Gas Intrusion Into Houses, Don Fugler, 2002.

Cost-Effective Concrete Repair: Research, Investigation, Analysis, and Implementation, Silvio Plescia, 2000.

Case Studies of Major Home Energy Retrofits, Don Fugler, 2003.

Basement Walls That Dry Quickly, Don Fugler, 1999.

Attic Ventilation and Moisture, Don Fugler, 1993.

Attic Moisture Survey, Don Fugler, 1990.

An Exploratory Study of the Climatic Relationships Between Rain and Wind, Jacques Rousseau, 1996.

Alternative Wall Systems for Low-Rise Housing, Darrel R. Smith, 2002.

Airtightness Tests on Components Used to Join Different or Similar Materials of the Building Envelope, Jacques Rousseau, 1998.

Airtightness Testing of Air Barrier Connection Techniques, Jacques Rousseau, 1991.

Advice on the Use of Chemical Strippers for Removing Leaded Paint, Don Fugler, 1992.

Air Filtration from Attached Garages in Canadian Houses, Don Fugler, 2001.

Advances in Basement Technology, Peter Russell, 1990.

Achieving Healthy Indoor Environments: A Review of Canadian Options, Thomas Green, June 2002.

A Survey of Problem Homes of the Environmentally Hypersensitive, Virginia Salares, 1996.

A Study of the Rainscreen Concept Applied to Cladding Systems on Wood Frame Walls, Jacques Rousseau, 1996.

2001 Building Failures Study, Luis de Miguel, 2001.

Fighting Mold – The Homeowner's Guide (About Your House CE 08)

Moisture in Canadian Wood-Frame House Construction Problems, Research and Practice from 1975-1991, Alvin J. Houston, 1993.

Moisture and Air: Problems and Remedies.

Investigation of the Performance of Gypsum Sheathing, Jacques Rousseau, 1998.

Removing Ice On Roofs (About Your House – CE 15).

The Importance of Bathroom and Kitchen Fans (About Your House – CE 17).

Measuring Sound Power Levels Generated by Fans – in Field Conditions, Jacques Rousseau, 1997, 1991.

Carbon Monoxide (About Your House – CE 25).

Attic Ventilating, Attic Moisture and Ice Dams (About Your House - CE 13).

Interaction Between Trees, Sensitive Clay Soils and Your Foundation (About Your House CE – 31).

Optimizing Residential Forced-Air HVAC Systems, Duncan Hill, 1996.

Exterior Insulated Finish Systems (EIFS) Field Performance Evaluation, Jacques Rousseau, 1998.

The Effectiveness of Low Cost Mechanical Ventilation Systems, Tom Hamlin, 1990.

Solving Persistent Moisture Problems and Moisture Damage

Ventilation and Air Quality Testing in Electrically Heated Housing, Don Fugler, 1994.

Energy Efficient Upgrade – Mechanical Systems (About Your House, CE28i)

Before You Start an Energy Efficient Retrofit – The Building Envelope (About Your House, CE 28J)

Combustion Gases in Your Home: Things You Should Know About Combustion Spillage (About Your House, CE2)

Atlantic Canada Wood Framing Moisture Survey, Terry Marshall, 1990.

Construction Problems in Multi-Family Residential Buildings, Jacques Rousseau, 1990.

Dawson City Demonstration Monitoring Northern Ventilation, Aleta Fowler, July 2003.

IRC Documents:

Dealing with Excessive Floor Vibrations, V. Young Benidickson, February 1993.

Building Envelope and Environmental Control: Part 1 – Heat, Air and Moisture Interactions, M.T. Bomberg and W.C. Brown, January 1993.

Towards Industrialized Construction, D.W. Finn, May 1992.

Integrating Windows with the Building Envelope, A. Patenaude, D.L. Scott, and M.E. Lux, November 1989.

Roof Functions, Requirements and Components, G.A. Chown, January 1990.

NRC/IRC:

Construction Technology Update No. 46. A Method for Evaluating Air Barrier Systems and Materials, Bruce Di Lenardo, December 2000.

Construction Technology Update No. 44. Curling of Concrete Slabs on Grade, Mr. N.P. Mailvaganam, Mr. J. Springfield, Dr. W. Repette, and Dr. D. Taylor, December 2000.

Construction Technology Update No. 25. Controlling the Transmission of Airborne Sound through Floors, A.C.C. Warnock, May 1999.

Construction Technology Update No. 17. Pressure Equalization in Rainscreen Wall Systems, M.Z. Rousseau, G.F. Poirier and W.C. Brown, July 1998.

Construction Technology Update No. 16. Sound Isolation and Fire Resistance of Assemblies with Fire Stops, T.R.T. Nightingale and M.A. Sultan, July 1998.

Construction Technology Update No. 15. Current Approaches for Mechanical Ventilation of Houses, J.C. Haysom and J.T. Reardon, May 1998.

Construction Technology Update No. 14. Why Houses Need Mechanical Ventilation Systems, J.C. Haysom and J.T. Reardon, May 1998.

Construction Technology Update No. 9. Evolution of Wall Design for Controlling Rain Penetration, G.A. Chown, W.C. Brown and G.F. Poirier, December 1997.

Construction Technology Update No. 5. Window Condensation in Historic Buildings that Have Been Adapted for New Uses, W.C. Brown, May 1997.

Six Axioms for Building Durable Concrete Structures, Noel P. Mailvaganam and G.G. Litvan, September 1997.

Other:

External Research Program Reports Arranged by Subject, Canadian Housing Information Centre, September 2003.

Current Housing Research (Volume 10, No. 1, 2003) (1095 KB)

Current Housing Research (Volume 9, No. 2, 2002) (921 KB)

Current Housing Research (Volume 9, No. 1, 2002) (845 KB)

Current Housing Research (Volume 8, No. 2, 2001) (1178 KB)

Current Housing Research (Volume 8, No. 1, 2001) (991 KB)

Energy Efficient Residence (EER) Literature

Description: EER was on of the two significant HUD research programs initiated in the 1970s and 1980s after the completion of Operation Breakthrough. The other program was the Joint Venture for Affordable Housing, which had more of an emphasis on land development and planning issues that the house itself.

EERs objectives were initially to find out how much energy could be saved in a home using off the shelf products and techniques. It addressed the cost and savings of various techniques, and their predicted and monitored performance. Subsequent to the first EER house, an EER-2 home was built. EER-2 was designed to explore more advanced measures that might become practical in the next five to 10 years.

Affiliation or sponsor:

US Department of Housing and Urban Development
Office of Policy Development and Research
451 7th Street
Washington, DC 21401

Contacts: All of the participants in this program are retired or moved on to other ventures. Orville Lee was the HUD GTR. Ron Yingling at NAHB RF is now at the Washington Suburban Sanitary Commission. Don Luebs, who managed the program, is retired from NAHB RF. Luebs was contacted as part of this review to discuss the program.

Specific projects or tasks applicable to systems thinking:

There were several final and interim reports that are of importance as follows:

1. EER – Research Results, Prepared for HUD by NAHB RF, principle investigator and project manager was Don Luebs. This is the published report for general dissemination on the first EER house. September 1980.
2. The Energy Efficient Residence, Research and demonstration to develop a optimum value engineered energy conservation home. Prepared for HUD by NAHB RF. Don Luebs, project manager. March 1981. This is the final project technical report on the first EER home.
3. The Energy Efficient Residence (EER-2), Demonstration and Evaluation of Energy Efficient Systems for Residential Structures. Prepared by HUD by NAHB RF. Don Luebs. October 1983. This is the final project technical report on the second EER home.
4. EER-2, Research Results. Prepared for HUD by NAHB RF. Don Luebs, project manager. July 1984. This is the published report for general dissemination on the second EER house.

We identified the following key reports that capture the major activities of the program.

Note that these are the reports identified by review of abstracts, descriptions or executive summaries that were subject to detailed review. There are other reports associated with OB that were identified but deemed non-relevant to our project goals. Details on specific projects or reports are as follows:

E1. EER – Research Results

Description/Scope: Report is the summary of results from the first EER in publication format intended for broad dissemination to the building industry. It summarizes the systems and characteristics in the EER home and a comparable conventionally-built home, presents the results of costs, benefits, and performance monitoring. It concludes with design tips for energy savings in homes.

How does this relate to systems approach:

a. Relates ceiling height as a design parameter to energy use by reducing the area of exterior walls.
b. Relates roof overhangs typically used for appearance and protection of openings from rain to energy use through shading of south facing windows.
c. Relates use of shade trees used for appearance to energy use through shading of south facing windows in summer.
d. Relates spacing of studs in finished basement to allow for increased insulation to be added (wall is set out from block foundation to form a wider cavity).
e. Relates OVE framing including two stud corners to reduction of framing factor to about 10%.
f. Relates use of plywood box headers, a cost reduction item, to increased energy efficiency.
g. Relates orientation of building and selection of window area to energy performance (on north and south facing walls)
h. Relates truss design at top plate to ability to increase insulation effectiveness in attic.
i. Relates use of ceiling-mounted fixtures for lighting to energy use.

j. Relates use of interior space to energy efficiency by placing all ducts in the conditioned space.
k. Heating and cooling equipment sized to consider the building's thermal resistance (sized to match needs not exceed them).

Data discussion: Not all of the features in the homes could be monitored separately to determine their impact, so some faith is required that they all contributed to the overall energy savings in the EER home versus the conventional home. For example items that use energy were monitored such as the HVAC equipment, but it was not possible to see how much shading of windows contributed to the savings.

E2. The Energy Efficient Residence, Research and demonstration to develop an optimum value engineered energy conservation home.

Description/Scope: This report is the final report on the first EER project. It contains descriptions of the techniques evaluated and results of monitoring of performance, cost analysis, and benefits. It is basically a more detailed report than discussed in Item 1 above.

How does this relate to systems approach: The same interactions between different systems as are described above for the more general EER document are also described in this report. Also, a vapor barrier originally was installed in the ceiling of the top floor. Although not documented in the report as related to the vapor barrier, Luebs (the author) believed that moisture problems that required use of a dehumidifier were later mitigated by removing the ceiling vapor barrier. The home apparently was too tight and retained too much moisture that condensed on some surfaces inside the home. The cost to heat outdoor air brought in by mechanical ventilation was viewed as too expensive a remedy for the moisture problem.

There is also discussion in more detail on the interaction between electrical systems and the energy performance. They describe use of surface mounted fixtures and receptacles, and elimination of wiring in exterior walls to reduce penetrations in the thermal envelope.

Data discussion: The more detailed nature of the data in this report provides stronger support for the interactions than the general EER report. Like the first report, it was not always possible to isolate some of the features so many were grouped together in the results.

E3. The Energy Efficient Residence (EER-2), Demonstration and Evaluation of Energy Efficient Systems for Residential Structures

Description/Scope: This is the final technical report on the EER-2 home. EER-2 was designed to take the EER-1 home to the next higher level by incorporating more advanced techniques for energy savings than the off the shelf items used in EER 1.

How does this relate to systems approach: Although there were many techniques used to increase energy efficiency in this home, most do not identify systems interactions that were not already identified in the EER-1 home (see previous list of interactions in Project numbers E1 and E2).

Additional issues of interest include:

1. The authors conducted analysis to estimate the solar gains and their relationship to the house performance and design of HVAC equipment. Additional emphasis was also placed on site selection to allow optimum orientation of the home on the lot.
2. They relate the installation of a ceiling vapor barrier to unintended moisture problems in the home.

Data discussion: For the most part, the data is well documented for the major systems performance, but they could not isolate many of the smaller sub-systems or items. The authors imply that the vapor barrier that was left out if the ceiling solved the moisture issue in the same home built under the EER-1 home, but there is no supporting measurements or other documentation. It may be that any number of other variables may have been the cause of moisture in the first EER home. And it is likely that other solutions, such as increased ventilation, could just as easily have solved the moisture issue.

E4. EER-2, Research Results.

Description/Scope: This is the published report for general dissemination on the second EER house. It contains energy efficient techniques used in the home, and performance results, costs and benefits.

How does this relate to systems approach: The same interactions as described for Projects E1, E2, and E3 apply for this report. There is no additional information of interest.

Data discussion: The level of supporting documentation in this report is not substantial. It was intended more for mass dissemination than for documentation. The final project report on EER-2 is better documented.

Environmental Protection Agency (EPA) Literature

EPA has two primary groups who conduct work directly related to housing systems and several others who sometimes flirt with these issues. The Indoor Environments Division is mainly working on large building and school issues. In the past, this group also handled much of the work on Radon in homes. They have a counterpart group in Research Triangle Park, NC in the Office of Research and Development, which is also focused on large and school buildings.

The Energy Star group also dabbles in some research that is probably more applicable to PATH's whole house efforts. They claim to have only actually funded two applicable projects. Mostly, Energy Star uses information developed by others.

EPA's documents are not easily accessible. Thus, we relied on personal communications with staff in these offices to identify the potentially-applicable documents.

EP1. Field Demonstration of Alternative Wall Insulation Products. Prepared by NAHB Research Center, May 1998, for Energy Star.

Description: Four production builders were selected to evaluate the cost and performance of groups of nearly identical homes built with different wall insulation systems. Systems included Blow-in- Blankets, spray cellulose, polyurethane foam spray insulation, and fiberglass batts. Each was compared to determine their overall impact on air tightness.

How does this relate to systems thinking: The study addresses the interaction between insulation type and air infiltration in homes. They authors conclude that there is not much of an interaction between the choice of insulation materials and infiltration. Careful attention to sealing and caulking of joints produced the greatest benefits toward reducing infiltration.

Data discussion: The findings are supported with field monitoring data.

EP2. **Field Investigation of Mechanical Ventilation Strategies in Residential Construction**, Prepared by Lyons et.al., NAHB Research Center, for US EPA, Indoor Environments Division and Energy Star, November 2001.

Description: The primary objectives of this project were to determine installed costs, operating costs, and measured whole-house air exchange created by mechanical ventilation systems in homes located in three climates in the United States. The report discusses selection of the systems, system and home designs, field monitoring of system performance, and first costs and operating costs.

How does this relate to systems thinking: The authors identify the possibility of depressurization resulting from operation of a mechanical ventilation system, especially those systems that are exhaust only. They provide measurements showing the ranges of expected pressure differences in these relatively tight homes.

Data discussion: The study is supported with extensive data from field measurements.

Forest Products Laboratory (FPL) Literature

Most FPL work is published on their website. It is not very search-friendly so the complete list of documents was reviewed to narrow it to the following.

F1. **Issues related to venting of attics and cathedral ceilings**, TenWolde and Rose, Ashrae Transactions, 1999.

Description: This paper discusses ventilation and its impact on attic temperatures, ice dams, shingle durability, and moisture. It is based on a review of the literature.

How does this relate to systems thinking: The authors show how attic ventilation interacts with other parts of the building. They show how it is necessary to consider indoor humidity and tight ceiling construction as primary methods to prevent condensation in attics from moisture migration from the interior. They suggest that ventilation is not supportable in cold/wet and hot/humid climates and that roof color has more impact on roof surface temperatures than attic ventilation. On the other hand, they do acknowledge the use of ventilation and the cool roof concept to prevent ice dams.

Data discussion: findings are base on review of the literature and expert opinions.

F2. Mold and decay in Tristate homes, TenWolde, no date but later than 1995 by references.

Description: Describes use of MOIST computer model to assess a group of homes that experienced significant deterioration of the plywood wall sheathing in the late 1980s.

How does this relate to systems thinking: The author shows the inter-relationship between tight homes, indoor humidity levels, ventilation rates, placement of vapor barriers and selection of wall materials. These items all work together and need to be considered as part of the systems approach.

Data discussion: Based on modeling results using MOIST. Supplemented with review of field reports by the author and others.

F3. FPL roof temperature and moisture model, description and verification., TenWolde, 1997.

Description: Document describes the FPL model for assessing roof/attic temperatures under various conditions. It compares the differences between the FPL model and the NIST MOIST model. A test home was constructed to compare modeled results with measured data.

How does this relate to systems thinking: The author identifies the different systems and subsystems that interact to affect attic performance. These include air infiltration of the home, air leakage from the home to the attic, solar radiation and reflectance of the roof covering (roof color), attic ventilation rate, and outdoor weather conditions. The interactions appear to be validated by the model comparisons with the measured results.

Data discussion: The author acknowledges that the model is not perfect, especially for certain extreme cases of high or low moisture in the sheathing. However, the conclusions appear to be well supported with good agreement for most of the measured versus modeled results.

F4. Rainwater Intrusion in Light-frame Building Walls, C. Carll, Forest Products Laboratory, 2000.

Description: Article describes problems and causes of rainwater penetration in homes. He also proposes an engineered approach to addressing problems.

How does this relate to systems thinking: The author paraphrases the findings from an investigation into a leaking condo project in Vancouver. Key interactions that led to rotting in recently-constructed multi-story wood-framed homes included:

- Lack of roof overhangs in a very wet climate.
- Aesthetic features such as cantilevered decks, bow and bay windows, inside and outside corners.

Data discussion: Mostly based on the author's expertise and review of literature.

Other FPL reports reviewed but not deemed relevant

Air pressures in wood frame walls, TenWolde, Carll, Malinauskas, no date given.

Lawrence Berkeley National Lab (LBNL) Literature

L1. **Publication or report: Saving tons at the register**, Walker, Siegel, Brown, and Sherman, No date given, but references in the report are as late as 1998.

Description/Scope: Describes an approach to properly size HVAC equipment based on delivered performance. Modeled results and a review of related work by others is included.

How does this relate to systems approach: The main point shown by the authors is the relationship between system sizing and duct system improvements. They claim that their modeling results show that the systems can be down sized without reducing cooling to the house or the pull down time when ducts are designed and built efficiently.

Data discussion: Conclusions are supported with references and modeling results.

L2. **Publication or report: Effects of duct improvements and Energy Star equipment on comfort and energy efficiency**, Walker et. al., July1999

Description/Scope: Two homes were assessed to examine how Energy Star equipment and other issues affect comfort and energy. The project included monitoring and system re-designs supported by modeling.

How does this relate to systems approach: The report shows how elimination of duct leakage and/or placement of ducts in conditioned space impacts the cooling equipment selection. Modeling results are presented showing how the system in a home was reduced from 4 to 3 tons.

Data discussion: Good connection between ducts, equipment, and energy use and comfort are presented. Monitoring results are presented, although for only two homes in two climates.

L3. **Publication or report: Case study field evaluation of a systems approach to retrofitting a residential HVAC system**, Walker et. al., 2003

Description/Scope: Report presents a case study of eight homes retrofitted for energy efficiency, with the emphasis on the envelope and ducts and their relationship to equipment sizing.

How does this relate to systems approach: Shows how tightening of the duct system and upgrading the thermal envelop can allow the equipment to be downsized. Also, presents case studies of the “systems’ approach that may be useful for later tasks under this PATH project.

Data discussion: Includes data from monitoring to support conclusions. Reputable source (LBL). Practical application of systems approach in that it was real-world and concessions had to be made to code officials and contractors.

L4. Publication or report: Characterizing the performance of residential air distribution systems, Mark Modera, June 15, 1993.

Description/Scope: 31 homes were subjected to field evaluations to diagnose issues related to duct system efficiency.

How does this relate to systems approach: The study identifies the placement of ducts as a contributor to comfort issues as they can cause unwanted ventilation from unconditioned spaces. They further determine that conductive losses can be significant in addition to air leakage from ducts.

Data discussion: Data from field diagnostics and modeling results are presented to support the findings.

Other LBNL documents reviewed but redundant, not deemed relevant or not enough detail.

Residential HVAC and distribution research implementation. Sherman and Walker, May 2002

Impacts on ventilation strategies on energy consumption and indoor air quality in single family residences, Hekmat, Feustel, and Modera, June 1986

Selecting whole-house strategies to meet proposed ASHRAE standard 62.2: energy cost comparisons. Wray, Matson, Sherman, April 2000

Dirty air conditioners: energy implications of coiling fouling. Siegel, Walker, Sherman,   no date but contains references as late as 2002

Simulations of sizing and comfort improvements for residential forced-air heating and cooling systems. Walker, Degenatais, Siegel, May 2002.

Field measurements of interactions between furnaces and forced air distribution systems. Walker and Modera, January 1998

Delivering tons to the register: energy efficient design and operation of residential cooling systems. Siegel, Walker, Sherman, No date provided, but sometime after 1998.

Distribution effectiveness and impacts on equipment sizing for residential thermal distribution systems. Walker and Seigel, June 1999

Window performance for human thermal comfort. Lyons and Arasteh, August 1999

Savings from energy efficient windows, Frost, Arasteh, and Eto, No date, but appears to be mid-1990s.

Transforming the market for residential windows: design considerations for DoE's efficient windows collaborative. Eto, Arasteh and Selkowitz, No date, but appears to be later than 1998 by reference dates.

Residential Air distribution systems: interactions with the building envelope. Modera and Jansky, July 1992.

National Institute for Standards and Technology (NIST) Literature

Almost all NIST reports are available on their website in pdf format. Keywords used include: Housing, hurricanes, buildings, building technology, HVAC, walls, moisture, systems, performance, Persily, Gross, and Wright (last three are authors)

N1. Baseline Measures for Improving Housing Durability, Office of Applied Economics, Robert Chapman and Christine Izzo, September 2002.

Description; This report examines the key sources of construction data and presents baseline measurements for use in monitoring progress against the PATH goals. It focuses on replacement frequencies and costs, and service life of various systems and subsystems.

How does this relate to systems thinking: This relates to the whole-house, systems project primarily in the way in which the authors define the various systems and subsystems. They provide examples of services lives according to major systems, subsystems in each major system, and components in each subsystem (Table 4-2). This identification system may be useful in formatting the whole-house calculator.

Data discussion: Compilation of data from the best available sources, although the information on services lives is not particularly strong.

N2. An indoor air quality performance standard for single-family residential buildings. A. Persily, 1999.

Description: Describes an ASTM (ASTM E6.66) effort to develop a series of performance standards for housing. This paper presents some of the requirements related to IAQ.

How does this relate to systems thinking: The paper describes the performance requirements of systems and subsystems related to IAQ. These include whole building requirements as well as at the system level.

Data discussion: The requirements described are based on developing standards using a consensus process.

N3. A computer analysis of wall construction in the moisture control handbook. Burch and Saunders, 1995.

Description: This report describes modeling results using MOIST. The assemblies evaluated are from the Moisture Control Handbook.

How does this relate to systems thinking: Describes the interactions that can occur between the selection of wall materials and moisture accumulation. The placement of a vapor barrier is particularly critical in hot, humid climates, where the author's suggest that no vapor barrier be installed. The cooling system may need to work harder to remove the small increase of latent load that may occur as moisture moves into the home from the outside.

Data discussion: Based on credible model, but the authors note that convective transport was not considered, nor was cyclic wetting by rain.

N4. Analytical study of residential buildings with reflective roofs, R. Zarr, 1998.

Description: Describes the use of the Thermal Analysis Research Program (TARP) to model the effect of roof solar reflectance on heating and cooling loads. Locations included Birmingham, AL, Bismark, ND, Miami, Phoenix, Portland, ME, and Washington, DC.

How does this relate to systems thinking: The results support that selection of roof coverings with higher solar reflectance (which usually means lighter color roofs) impact the energy use in a home. The benefits are limited to the cooling season. Higher solar reflectance can be detrimental for heating. The same relationship was concluded for increasing attic ventilation (increased ventilation was beneficial at reducing cooling loads and detrimental for heating).

Data discussion: Findings are based on modeling exclusively.

N5. ASTM E06.66 Performance Standards for Dwellings

Description: ASTM formed a consensus subcommittee under their E06 committee to develop performance standards for homes. NIST provided extensive support for this project, as did HUD, even though it is technically an independent standards effort.

How does this relate to systems thinking: A key activity in developing a systems approach for housing is the ability to develop performance criteria for each subsystem. Many organizations have attempted various parts of this criteria development over the past several decades. Code and standards bodies and government agencies in Australia, Sweden, Japan, the Netherlands, Israel, and the United States have all attempted to tackle this very complicated subject in whole or in part.

The Subcommittee E06.66, Performance Standards for Dwellings, has been working to assimilate the work to date on performance attributes into a set of standard guides for home building. To date, ASTM has completed a guide on durability and one on the economic evaluation of alternative designs, systems and materials. Guides on indoor air quality and acoustics are under development.

Data discussion: The ASTM work initially was focused on developing “hard” standards but after several attempts, the subcommittee is now focusing on guides. This reflects some of the challenges to the whole-house approach that will also be faced under the PATH program. The ASTM group did not fully understand the human side of the systems approach. In setting criteria that is based on human expectations, such as floor vibrations in a structural system or thermal comfort, the definition of acceptable or minimum performance is not only dependent on technical performance but also on somewhat subjective definitions. There was strong building industry resistance to these activities and many of the guides are stalled because of the resistance.

Other NIST documents reviewed but redundant, not deemed relevant or not enough detail.

An analysis of moisture accumulation in the roof cavities of manufactured housing, Doug Burch, 1995.

Structural performance of wood frame housing: State of the art and research needs, Sadak and Gross, 1999

Manufactured housing walls that provide satisfactory moisture performance in all climates, D. Burch, A. tenWolde, 1995.

Operation Breakthrough (OB) Literature

Description: OB was a 1970s HUD program designed to form partnerships with industry to “improve the process of providing housing.” OB was in response to the goals of Congress to built 26 million homes in a ten year period. The emphasis of OB was on processes that incorporated all or part of the construction in a manufacturing environment.

The program was divided into Type A and Type B activities. Type A contracts were awarded to housing producers to design and build innovative homes. Type B contracts were technical activities in support of the Type A work. The Type B contract work is more relevant to systems design and construction whereas Type A is more related to whole-building systems.

Affiliation or sponsor:

US Department of Housing and Urban Development
Office of Policy Development and Research
451 7th Street
Washington, DC 21401

Contacts: Very few people are still around with direct involvement. Dave Engle at HUD, Phone: 202.708.4370, may be the best source of information on the Type A work, since this was considered the heart of the program. David Hattis of Building Technology also was involved in the Type A work. On the Type B work, Don Luebs, NAHB Research Foundation (retired) is as good as any of the contacts on the technology-related work. Also, a few people may still be at NIST who worked on Type B contracts.

Specific projects or tasks applicable to systems thinking:
Although there are many news articles and fluff pieces on OB, the program suffers from a lack of documentation at the technology level. We identified the following key reports that capture the major activities of the program:

1. Guide Criteria for the design and evaluation of Operation Breakthrough Housing Systems, Volume IV – single family detached. Prepared by National Bureau of Standards (Now NIST), September 1970. No specific author listed.
2. Operation Breakthrough Phase I design and Development of Housing Systems. Prepared by the Boeing Company, David C. Kirkman. No date on the document, but from the text references to other activities, it was sometime around 1971.
3. The Comparison of Phase II OB Housing with Matched Conventional Housing, prepared by National Bureau of Standards, Stephen Margulis et. al, December 1974.
4. The Impact of OB on the Nation's Housing Industry, Prepared by Real Estate Research Corporation, Building Technology Inc., and Arthur D. Little Inc. No specific authors listed, July 1976.
5. Optimum Value Engineering Building System, NAHB Research Foundation, January 1973. This is the final report on testing and analysis that led to the better-known publication "Reducing Home Building Costs with OVE Design and Construction." Don Luebs was PI or co-PI on both documents.

Note that these are the reports identified by review of abstracts, descriptions or executive summaries that were subject to detailed review. There are other reports associated with OB that were identified but deemed non-relevant to our project goals. Details on specific projects or tasks are as follows:

O1. Guide Criteria for the design and evaluation of Operation Breakthrough Housing Systems, Volume IV – single family detached.

Description/Scope: This document is a set of performance criteria with commentary for homes built under OB. It addresses criteria according to 12 subsystems.

How does this relate to systems approach: First, this relates to Task 6 in that it describes the home according to 12 subsystems:

1. Structure
2. Walls and doors, inter dwelling
3. Walls and doors, intra dwelling
4. Floor-ceiling, interior
5. Walls, doors and windows, exterior envelope
6. Roof-ceiling, ground floor
7. Fixtures and hardware

8. Plumbing
9. Mechanical equipment, appliances
10. Power, electrical distribution, communications
11. Lighting elements
12. Enclosed spaces.

Second, there are a couple of subsystem interactions either directly discussed or implied:

1. Malfunctioning windows due to excessive deflection of structural elements (p. A.1.3)
2. Distortion of exterior cladding due to not considering differential temperature-driven volume changes (p.A.1.7)
3. condensation on structural materials due to lack of vapor barriers or other moisture control strategies (p.A.8.1 (2))
4. Thermal breaks in highly-conductive materials used in the envelope (doors, panels, windows) to prevent condensation (p.E.7.2).
5. Importance of considering windows and doors in assessing water leakage (p.E.7.4(2)). The need for flashing is not addressed but implied as the solution.
6. Need for a vapor barrier on warm in winter side of walls and ventilation between insulation and outside wall material to address condensation (p.E.7.6).
7. Need for a ground cover in basement-less (Crawlspaces) spaces exposed to soil to prevent moisture build-up in living areas (p.F.7.6 (2))
8. Protection of water supply pipes from other materials and soils (p.H.8.6).
9. HVAC equipment designed and installed to reduce noise (p.I.5.1). Especially important as we move more into the conditioned space.
10. Mechanical ventilation in tight buildings (p.I.7.3)

The interactions stated above are not supported by references or data. Rather, they are based on the authority of the authors (NBS) or building codes or similar reference documents.

Data discussion: No new research was attempted under the work described under this report. The findings are based on reviews of existing literature and expert opinion. They were not directly focused on interactions between systems or sub-systems, but the report does either directly cite some potential interactions or indirectly implies them.

O2. Operation Breakthrough Phase I Design and Development of Housing Systems.

Description/Scope: This document is a compendium of the 22 housing systems that were selected by HUD for construction as demonstrations under OB. It provides an overview of the systems, their design approaches, descriptions of various subsystems, and innovations used by each manufacturer. The report was compiled by an editor for the Boeing Company based on design and related information provided by the individual manufacturers.

How does this relate to systems approach: One objective of the design stage for the homes was integration of the various sub-systems. It is not perfectly clear just what this meant to each participant, as the document does not define it nor document how they went about it. However, there are a few systems interactions either directly cited or at least implied in the various system descriptions. These include:

1. Multiple projects with service modules designed to help disentangle the utility systems. Most of these modules include a prefabricated kitchen or bath core. One of the more interesting ones has the HVAC equipment already installed in the module ready for connection to the ductwork. The structural systems are of various materials, some of which seem to downplay the need for access to the wall cavities. At least one is a system with the complete inside of the module finished while the outside is open to allow the wiring and other utilities to be installed on-site.
2. The interaction of the structure and the finish is recognized by the use of adhesives to eliminate nail pops (p.105).
3. The interaction of the floor structure with the sheathing is recognized by a T-beam design that uses 2x6 floor joists (p.105).
4. Hinged overhangs on modular systems that address the need to shed water away from walls (p.117). Note: most modular homes come without overhangs due to limits on shipping width.
5. Small diameter ducts to facilitate routing (p.117).
6. British single stack plumbing system (p.117). It is not clear what this is but it appears to be a simplification to the practice of using multiple stacks.
7. Electrical raceways for closed panel systems (p.149).
8. Pre-fabricated plumbing trees (p.149).
9. Sandwich panels (SIPs type product with insulation, structure, and exterior pre-finished) (p 149).

Data discussion: This report does not describe how various interactions were considered between systems or sub-systems. It only cites a handful of interactions as areas they considered in design. Supporting data is not provided, although it was likely produced at some point in the process.

O3. The Comparison of Phase II OB Housing with Matched Conventional Housing

Description/Scope: This report presents the results of interviews with 1481 OB home occupants and 551 conventional home occupants on their likes and dislikes about home performance.

How does this relate to systems approach: The interview results open up a part of systems design that is often overlooked – the consumer's level of satisfaction with innovative approaches or changes in homes. Unfortunately, the answers were limited to a set of statements presented to the interviewees. There were no follow-up questions to identify why certain parts of the home were liked or disliked. For example, the OB occupants were less satisfied with the HVAC systems and the bathrooms than the conventional housing occupants. However, the report does not specify exactly what it was they did not like.

Data discussion: After detailed review of this report, it is not likely to be helpful in our attempt to build a calculator describing systems interactions. The level of detail is not sufficient to identity specific interactions.

O4. The Impact of OB on the Nation's Housing Industry

Description/Scope: The purpose of this study was to assess OB's impact on certain parts of the building industry. It focused on the impact on code groups, financial institutions, governments, unions, consumers, and the transportation sector. More applicable to our study, it contains mini case studies of the housing manufacturers and their systems including technical changes that were instituted as they moved into production.

How does this relate to systems approach: Several of the modifications necessary to move the systems into production raise issues that impact the ability to use a systems design approach in the real world. The major modifications are described as follows:

1. The manufacturers systems turned out to be too complicated for low-rise homes. They tended to "de-engineer" the systems and replace higher-tech materials with conventional materials that requires less precise jointing methods and were considered "safer."
2. The modular system producers almost all moved to a panel system over time because of transportation issues. Even some of the modular producers had to reduce the size of their modules which removed any added efficiency they brought to the table.
3. Several manufacturers' panel systems suffered repeated damage to the surface of their panels during shipping and handling. There was no one at the site who could do the repairs.
4. The choice of roof framing was changed to allow round ducts. (Note, this interaction is even more important today given the wider selection of structural systems).
5. A fiber-shell finish material was replaced with conventional materials due to excessive thermal expansion. The panels were 30 foot long without means for expansion.

Data discussion: This report points out some of the practical difficulties in implementing a systems approach that relies on innovative materials. It also identifies a few minor interactions including those between ductwork and structural systems and thermal expansion issues related to cladding. Overall, there are no major interactions cited.

O5. Optimum Value Engineering Building System.

Description/Scope: This report is a final report on a Type B OB contract issued to the NAHB Research Foundation. It addresses development of the Optimum Value Engineering (OVE) system for housing construction. Included is a review of the research that supported the more-widely distributed OVE manual, descriptions of the OVE methods, a chronology of the prototype OVE house, and problems encountered in the design and construction of the home and their solutions.

How does this relate to systems approach: First, this report breaks down the home into various systems and subsystems as follows:

1. Foundations
2. Floors
3. Exterior wall systems (including siding, windows and doors)
4. Roofs (including sheathing, covering, and trim)
5. Interior partitions (including doors, wall board, trim, closets, paint, and cabinets)
6. Mechanical (including heating, plumbing, and electrical)

Each of these is broken down further depending on the specific system. For example, the walls are broken down to elements as small as the top and bottom plates.

Second, the project represents one of the first attempts to systematically integrate many of the major systems of a home. The main emphasis is on reducing costs, mainly with the structural and envelope systems, but it documents how these systems need to be examined in light of the other systems in the home. In some ways the report gives one of the clearer descriptions of what they mean by "systems" design. Basically they address the changes they planned to make in phases by first identifying the innovations or changes, conducting analysis of alternative subsystems to optimize each one, and integrating the chosen innovations into the total building by considering impacts on other systems. Specific subsystems to consider are suggested for the designer.

Third, the report identifies directly or implies interactions that may be considered for the whole-house systems calculator. These include:

1. Plan location of flue, ducts, plumbing, etc to be compatible with the structural system
2. Eliminate overhangs. This is of interest because it is suggested as a cost reduction feature but there is no mention of the benefits of overhangs in protecting openings from rain fall. They do recognize that overhangs are useful in moving water from to roof away from the foundation by suggesting that you can keep the overhang as an alternative to gutters.
3. Clustering of plumbing and single stack DWV system to reduce the interference with other systems
4. Sizing of the HVAC systems using manual j in consideration of the relatively high insulation levels used in the building envelope.
5. Use of a central trunk in the main hallway with short duct runs to the adjacent rooms on the interior of the building (as opposed to washing windows and the exterior walls). Although not specifically mentioned, this had the effect of reducing duct losses and moving the duct system within the conditioned space.
6. Truss designs to eliminate partition separation.

Data discussion: This project basically laid the groundwork for much of the systems integration work that has followed it. Perhaps the best system interaction attributable to OVE is one that is not mentioned in the report but which has been adopted by others including DoE's Building America under the term "advanced framing." This is basically the OVE concept contributing to increased energy efficiency by minimizing framing factors in the thermal envelope.

This report does not actually provide data to support its conclusions. Rather, it summarizes test data and other information from previous work by the same authors and others. It does provide specific references for most of its claims. The bulk of the underlying supporting work was also funded by HUD under OB or in earlier research projects.

PATH and Other Misc. HUD Literature

Program/Project: Partnership for Advancing Technology in Housing (PATH)

Description: PATH is a program at HUD in cooperation with other agencies. The program has a series of goals designed to improve affordability and increase the value of homes relative to environmental impact, energy efficiency, durability, and safety through the use of innovative technology. The program has been in existence since 1997 and has had an annual budget between $7.5m to$10m. The program is designed to involve many different parts of the industry and the agencies involved in housing.

Affiliation or sponsor:

US Department of Housing and Urban Development
Office of Policy Development and Research
451 7th Street
Washington, DC 21401

Contacts: Dana Bres, Dave Engel
Office Phone: 202.708.4370
Program web site: www.pathnet.org

PATH projects funded through early 2003 are listed at the end of this section. Specific projects or tasks that may be applicable to whole house or systems thinking were identified and include the following:

1. Field Evaluations. These are probably the most applicable, since they include both supporting research and field monitoring. Many of the evaluations address durability issues that are impacted by changes in one system or another.
2. Housing Durability (including manufactured housing research)

Details on specific projects or tasks:

P1. Field Evaluations

Description/Scope: The PATH Field Evaluations are designed to answer questions about specific technologies and how they work during design, installation, and occupancy. To date, there are 32 on-going or complete evaluations listed on the PATH websites. A few have reports, but most available information is limited to the web pages on each project.

How does this relate to systems approach: There are a few of the evaluations where interactions between different systems in the home were studied or resulted from the evaluations. These are discussed below under findings.

Findings:

Site 1. Bruce Davis Construction, La Plata, MD. The research team examined the concept of installing ducts in the conditioned space, as opposed to the builder's conventional practice of placing them in the attic. Although the duct system design was very efficient, it created a secondary problem that many designers may not consider. Because the homes were on slab foundations, the logical place to put the duct work was by dropping the ceiling in the main hall way and using a bulkhead through one of the other rooms on the first floor. The use of bulkheads to hide the ducts inside the living space was not acceptable to the owner for appearance reasons.

References/contacts for Bruce Davis Construction: There were many staff involved in this project at the NAHB Research Center. Margo Thompson at NAHB was one of the staff. Other key personnel with insight on this finding include Mark Nowak at Newport Partners LLC, Davidsonville, MD and Chad Garner at Wise Choice Construction, Hughesville, MD.

<u>Site 2. Hughes Construction, Lexington, NC.</u> This evaluation consisted of a comparison of the performance of wood framing to three different wall systems: AAC, steel/foam panels, and ICFs. The evaluation focused on energy performance, sound and costs. Two small interactions were identified that may be relevant to some types of homes. First, the selection of structural or insulation systems that result in a thicker wall need to be coordinated with the selection of finishes such as doors and windows. Wider trim packages are typically required. Second, FSTC tests showed a relationship between openings and sound performance. Walls with windows and doors performed at about the same independent of the wall construction. Results of energy performance testing are pending.

Contacts for Hugh Construction project: Marie Del Bianco, NAHB Research Center, PI.

<u>Site 3. K. Hovnanian Idea House, Freehold, NJ.</u> The team attempted to move the entire HVAC system inside the conditioned space, not a typical practice in this region. The builder resisted construction of bulkheads in the family room for aesthetic reasons and a small portion of supply was routed through the garage. They also took advantage of a systems effect between the envelope and the HVAC system by using a minimized duct system. Registers were not located at the perimeter under windows as is typical practice in NJ, but on interior walls to minimize duct runs. The builder also will be able to downsize the HVAC units because of the increased performance of their envelope and windows.

K. Hovnanian Idea House contact. Jamie Lyons was the PI. He is now with Energetics, Columbia, MD.

<u>Site 4. Warren Builders, Albertville, Alabama.</u> The main systems effect noted in this project is that combinations of system "improvements" can create unwanted results. With Warren Builders, the combination of improved envelope, tight construction, ducts in conditioned space, and mechanical ventilation resulted in an increase in annual operating costs. Isolating the ductwork in conditioned space showed this technique by itself produces an annual savings. The introduction of ventilation air caused an increase in the heating and cooling loads (sensible and latent) that resulted in the overall increase of the combination of systems. The latent cooling load introduced by mechanical ventilation had to be considered in HVAC sizing. Also the use of bulkheads inside the conditioned space for duct work impacted the drywall contractor, who had to make an extra trip to finish and paint the bulkheads. This study is supported by extensive field monitoring and modeling.

Warren builders project contact: James Lyons (PI) formerly with NAHB Research Center, now with Energetics, Columbia, MD.

Site 5. Henderson, Nevada retrofit. This study showed how the envelope and duct work interact with HVAC equipment. Improvements to the home allowed the HVAC unit to be reduced from 3 ton to 2-1/2 tons. The placement of ducts in attics was also shown to be energy inefficient. The project is supported by data collection and modeling.

Henderson project contacts: Craig Drumheller, NAHB Research Center

Site 6. MADE Homes, Bowie, Maryland. This evaluation was more of a demonstration of techniques to build homes that are marketable, affordable, and durable. The participants took a systems approach to optimizing durable features and balancing them against the need for integration into the other systems and the community.

Durability Projects

There are several major reports relevant to this part of PATH. These are reviewed below.

P2. Housing Durability Assessment, prepared for HUD by NAHB Research Center, November 2001, Phil Davis and Jay Crandell

Description: A study was commissioned of a representative sample of homes in Anne Arundel County, Maryland to evaluate durability issues and identify ways to improve performance. A total of 211 homes were subjected to field assessments and home owner surveys.

How does this relate to systems approach: Poor grading (toward the home as opposed to moving water away) was correlated with foundation cracks. Selection of wood trim was correlated with exterior rot issues. The size of roof overhangs decreased over time and was believed to contribute to rot problems.

Data discussion: Good size representative sample. Physical inspection and survey combined approach. Limited to one county in Maryland.

P3. Assessing Housing Durability: A Pilot Study, (same report and date as above in Item 1, but published under a different name)

P4. Water Intrusion Evaluation for Caulkless Siding, Window, and Door Systems. January 2002. Prepared for HUD by NAHB Research Center, Upper Marlboro, MD. Chad Garner .

Description: Lab tests were conducted to evaluate water penetration into various walls. Emphasis was placed on well-designed flashing systems around openings.

How does this relate to systems approach: The use of caulking is often relied on to prevent moisture from entering a wall. The results show this is not a good practice as a stand alone item. The practices that prevented moisture from entering a cavity were the use of appropriate flashing around openings and a method for water to drain that does get behind the siding. The flashing methods used performed well, but they require some of the flashing to be installed prior to window installation, which is not common practice.

Data discussion: Tests were run in accordance with an ASTM consensus standard method.

P5. Moisture Problems in Manufactured Homes, Prepared for HUD by MHRA, Francis Conlin (Project coordinator), 2002.

Description: A manual for manufacturer home producers, designers and installers to assist in reducing or eliminating moisture problems.

How does this relate to systems approach? Include a checklist of items to avoid unwanted interactions between systems and sub-systems in homes. These include:

- Minimizing ceiling penetrations to prevent moist air from escaping and possibly forming mold in the attic.
- Eliminating the vapor barrier on inside of wall in hot-humid climates to prevent condensation inside the cavity.
- Use care to eliminate cold spots when insulating.
- Properly size cooling equipment to eliminate excessive cycling and interior moisture problems..
- Seal ducts.
- Properly grade the site.
- Use a ground cover over exposed soil to eliminate ground moisture as a source.

Data discussion: Based on experience and opinion of MHRA staff and an expert review group. Intended for wide dissemination.

P6. Attic Ventilation Design Strategies for Manufactured Homes, Prepared for HUD by MHRA, Emanuel Levy, October 2002.

Description: This document presents a review of literature related to moisture in attics and presents a research plan for hot, humid climates.

How does this relate to systems approach: The issue of attic ventilation overlaps with multiple subsystems in the home. This report identifies the purpose of attic ventilation to be fourfold – to control moisture, for energy conservation, for shingle durability, and for ice dam prevention. In hot and humid climates, venting to the outside may increase moisture levels in attics. However, all codes require attic ventilation independent of the climate. And there are other steps that should be taken if attic ventilation is not used to control moisture including tight ceiling construction.

Data discussion: Conclusions are based on an extensive literature search, although the literature cited is not unanimous in supporting the suggestion that attic ventilation can be eliminated.

P7. Minimizing Moisture Problems in Manufactured Homes located in Hot, Humid Climates. Prepared for HUD by MHRA, Emanuel Levy, September 2003.

Description: A series of tests were conducted on two manufactured homes to profile air flows under varying conditions. The objective was to develop moisture mitigation strategies for homes in hot, humid climates.

How does this relate to systems approach: Eight factors were identified that inter-relate with pressure profiles in homes: duct leakage, shell leakage, interior airflow, exterior air barriers, air supply balance, return air grill opening size, exhaust fan operation, and passive ventilation. They conclude that duct leakage and shell leakage have the greatest interaction with pressures in the homes and thus moisture control in hot, humid climates. Tight envelopes can exacerbate negative pressures if ducts are not tight and proper attention is not paid to duct return design. Using a sheathing that is an effective air barrier will minimize intrusion of moisture in hot, humid climates.

Data discussion: Supported by field measurements on two homes.

Other relevant HUD research:

P8. Assessment of Damage to Single Family Homes Caused by Hurricanes Andrew and Iniki, prepared for HUD by NAHB Research Center, Jay Crandell. September 1993.

Description: Report consists of a field study of 500 homes in Florida and 160 in Hawaii to determine why some buildings suffered damage, the rate of damage, and types of damage to different buildings.

How does this relate to systems approach: The results show important interactions between parts of the home and performance of the home in high winds. The selection of roof type is important, with hip roofs performing better than gable end roofs. Selection of roof coverings that do not resist high winds contributed to extensive water damage. Attachment of roof sheathing was also inadequate in many of the severely damaged homes.

Data discussion: Findings based on relatively large random sample.

P9. Tornado, Disaster Analysis teaches How to Build Better, Volume 1, No.1 *Housing R&D*, by Jay Crandell et. al., NAHB Research Center. Fall 2002.

Description: This article was based on work funded by others but published in a magazine as part of the Toolbase-funded PATH program. The study includes results of a field study of the 2002 La Plata, MD Tornado, which may have been as high as an F-4 tornado.

How does this relate to systems approach: The main point is related to the selection of the thermal insulation and its interaction with the structural performance. The authors recommend using full structural sheathing (versus foam insulation with bracing) to reduce the chance of structural damage in areas outside of the vortex but still subject to high winds. This represents a large area along the path of a tornado.

Data discussion: Authors used field data but they do not suggest the sample is random.

P10. Durability by Design: A Guide for Residential Builders and Designers, by Jay Crandell et. al., NAHB Research Center for HUD, May 2002.

Description: This manual provides practical "how-to" information for the design of homes, with a primary emphasis on prevention of moisture problems. It also addresses sunlight exposure, insects, and natural hazards.

How does this relate to systems approach: The interactions of various parts of the home as related to moisture are discussed. Examples include the impact of roof overhangs on protection of wall openings, the impact of grading and roof drainage on interior moisture problems, and the impact of roof slope or number of stories on structural performance.

Data discussion: The document references many other works to help derive some of the suggestions. However, some of the suggestions are based on common sense interpretations of the literature and the experience of the authors, rather than on specific scientific works.

PATH work funded through early 2003:

1. PATH Cooperative Projects and Industry R&D
    a. Manufactured Housing Technology Research
        i. *Root Causes of Moisture Damage in Manufactured Homes*
        ii. *Evaluation of Foundation Systems*
        iii. *Develop a DAPIA Approved Design for Cold-Formed Steel Framing*
        iv. *Regulatory Hurdles to Use of Manufactured Homes in Attached Housing*
        v. *Conduct Manufactured Housing Double Wide Structural Analysis*
    b. Steel Framing Alliance
        i. *Screw Corrosion Study*
        ii. *Hybrid Connection Details*
        iii. *Steel Framing Alternatives for Manufactured Housing*
    c. NAHB Research Center
        i. *Development of Building Applications for Dow's Vacuum Insulation Panel Technology*
        ii. *Research on Alternatives to Wood*
        iii. *Advanced Residential Building Technology*
        iv. *Develop Four Marketable, Affordable, Durable, Entry-Level (MADE) Homes*
        v. *Develop a Quality Alliance with Builders and their Trade Contractors with the Wood Truss Council of America*
        vi. *ToolBase*
        vii. *Demonstrations and field evaluations*
        viii. *Technology inventory and scanning*
        ix. *Roadmapping*
        x. *Framer quality program development*
    d. Stephen Winter Associates
        i. *Demonstrations and field evaluations*

   ii. *Technology inventory and scanning*
   iii. *Roadmapping*

e. VA Tech
   i. Industrialization of the Job Site

f. William H. Porter Associates – *Development of an Alternative SIPS System*

g. CertainTeed Corporation – *Develop a "Supersub" Trade Contractor Homebuilding Process Approach*

2. National Science Foundation Grants

   a. FY 2000 NSF Grants to Universities

      i. North Carolina State University
      Precast Post-Tensioned Clay Masonry Walls for High-Performance Modular Housing
      ii. North Carolina State University
      Adaptive Shading Technologies for Future Housing
      iii. Arizona State University
      Skill-Driven Optimization of Construction Operations
      iv. North Carolina State University
      Experimental Assessment of Site-Integrated Planning and Information Technologies in Residential Construction
      v. Michigan State University
      Modeling of Manufactured Housing Production and Material Utilization
      vi. University of Wisconsin at Madison
      The Interdependency of the Fire Protection Membrane and the Structural Response of Light-Frame Engineered Wood Floors and Ceilings
      vii. Louisiana State University 's Agricultural Center
      Durability Analysis of Structural Oriented Strandboard Made With Borate-Modified Wood Flakes
      viii. Clemson University
      Fragility Methodology for Performance-Based Engineering of Light-Frame Residential Construction
      ix. University of Wyoming
      Prediction of Manufactured Home Durability Using Field Experiments in Hazardous Winds
      x. Rensselaer Polytechnic Institute
      Eave Icing of Residential Buildings
      xi. University of Maine
      Optimized FRP-Reinforced OSB Panels for Disaster Resistant Construction

   b. FY 2001 NSF Grants to Universities

      i. Rensselaer Polytechnic Institute
      Rigidified Pneumatic Composites: Use of Space Technologies to Build the Next Generation of American Homes

ii. University of Washington
Microcellular Polymers Processing for Lightweight and Energy Efficient Advanced Panel Systems
iii. Pennsylvania State University
Moisture Control: Convective Drying in Residential Wall Systems
iv. University of Kansas
Numerical Analysis of Transient Slab-on-Grade Heat Transfer
v. Michigan State University
Biocomposites from Engineered Natural Fibers for Housing Panel Applications
vi. Georgia Tech Research Corporation, Georgia Institute of Technology
An Integrated Program to Examine the Moisture-related Performance of Fiber-cement Composites
vii. Virginia Polytechnic Institute and State University
Designing Panelized Systems to Minimize Impact on Indoor Air Quality in Tightly-Sealed Buildings
viii. Northwestern University
Extruded Fiber-Reinforced Cement Composites for Residential Construction
ix. University of Delaware
An Advanced All Natural Composite Roof for Residential Construction
x. Virginia Polytechnic Institute and State University
Advanced Replacements for Mechanical Fasteners in Housing Construction for High Wind Zones
xi. Oklahoma State University
Engineered Wood Frame Wall Panel System Integrating Prefabricated Truss Technology

c. FY 2002 NSF Grants to Universities

i. University of Southern California
Automation of Whole House Construction Using Contour Crafting
ii. Massachusetts Institute of Technology and University of Central Florida
Collaborative Research: An Integrated Interior Infill System for Mass Customized Housing
iii. Purdue University
Manufactured Housing Production Process Analysis and Facility Layout
iv. University of Missouri Rolla
Renewable and Resource Efficient Composite Materials for Affordable Housing
v. Villanova University
Using Viscoelastic Material to Reduce the Dynamic Response of Woodframe Structures
vi. Virginia Polytechnic Institute and State University
Whole House Design through the Application of Multi-functional Precast Panels

3. PATH Cooperative Research Program (CoRP) through NIST

a. FY 2000 Grants Through NIST
   i. AeRock, LLC, Littleton, Colorado
      Innovative Fiber Fly Ash Composite Structural Insulated Panel Building System
   ii. Steven Winter Associates, Inc., Norwalk, Connecticut
      Development of an Energy Saving Thermostat with Variable Deadband Control for Residential Buildings
   iii. Benchmark Resources, Inc., Auburn Hills, Michigan
      Insulated Concrete Panel Technology
   iv. W. Brandt Goldsworthy & Associates, Inc., Torrance, California
      Goldsworthy Innovative Fabrication Technology (GIFT) Housing
   v. Persimmon Homes, LLC, Washington, Georgia
      Creating a Building System Optimized for Delivering Affordable, Durable, and Energy Efficient Single-Family Homes to Locations Where Construction Tradesmen are Scarce
   vi. PowerLight Corporation, Berkeley, California
      SunTile Solar Roofing: Natural Cooling and Electricity Generation

4. PATH Funded Work Through Other Agencies

a. U.S. Department of Energy
   i. Development of Electrochromic Glazing Technology
   ii. *Support to the DOE Weatherization Program*

b. U.S. Department of Agriculture/Forest Products Laboratory
   i. Outdoor durability of wood-plastic composite lumber
   ii. Panelized roofing systems made from natural fiber and recycled plastic
   iii. Predicting the life span of sealants used in home construction
   iv. Increasing the Marketability of Reclaimed Lumber
   v. Decay of wood and wood composites under cyclical conditions
   vi. Reliability of residential buildings

c. U.S. Department of Commerce/National Institute of Standards and Technology
   i. Building for Environmental and Economic Sustainability (BEES)
   ii. National Economic Service Life Tool (NEST)
   iii. Internet Decision Support System for Durability in Housing (PATH-D)
   iv. Service Life Prediction of Polymeric Coatings

d. U.S. Environmental Protection Agency
   i. Support for the Building Performance Institute's Development of a Certification Program

Trade Press Literature

Description: The main trade press that covers the building industry and specifically systems design and related issues includes *Journal of Light Construction* (JLC), *Builder* and *Big Builder* (both accessible through Builderonline.com), *Professional Builder*, *Professional Remodeler*, and *Luxury Home Builder* (all accessible through Housingzone.com), *Fine Homebuilding*, and *Home Energy Magazine*.

Affiliation or sponsor:

These are all trade publications.

Contacts: *JLC*: Archives are accessible through a password protected web site with a membership fee. www.jlconline.com

Builder, Big Builder: Archives accessible through www.builderonline.com

Professional Builder, *Professional Remodeler*, and *Luxury Home Builder*: Archives accessible through www.houzingzone.com

Home Energy Magazine: Archives accessible through www.homeenergy.org

Specific articles applicable to systems thinking:

T1. **Are your houses too tight?** August 1994, JLC.

Description/Scope: Written by Gary Nelson and Gary Anderson of the Energy Conservatory, Minneapolis, this article provides an overview of air tightness issues with emphasis on interactions between various systems and subsystems.

How does this relate to systems approach: Several interactions are identified. Several of these are based on field diagnostics work and could thus be considered mini case studies of system interactions. These include:

1. Condensation due to higher humidity levels when inadequate ventilation is present.
2. Backdrafting due to natural draft appliances competing for combustion air and causing combustion products spillage into very tight homes.
3. Backdrafting of water heater due to return duct leaks in basements.

The authors provide recommendations for new construction in very tight homes including using only sealed combustion equipment or fan assisted exhaust, and exhaust fans in all kitchen and bath areas to reduce moisture levels.

Data discussion: Although not thoroughly documented nor representative of the housing stock, the authors provide results from their own diagnostic work. Thus, they demonstrate that these types of interactions can occur in actual homes.

T2. **Make-up air for combustion equipment**, December 1999, JLC

Description/Scope: Describes the need for make-up air and how to avoid backdrafting from other causes.

How does this relate to systems approach:

1. Lack of make-up air in tight homes can cause backdrafting

2. Cool chimneys (e.g., located on outside wall or far from the combustion source) can cause backdrafting.

Data discussion: This article is based on the expert knowledge of the author and building science theory. Although it identifies several interactions, there are no field data or other supporting research cited.

T3. **Backdrafting causes and cures**, December 1990, JLC

Description/Scope: Describes several scenarios for backdrafting to occur and how to avoid it.

How does this relate to systems approach: Gas and oil furnace spillage are cited as issues in 10 to 15% of homes. The author cites his own work in a 1986 field study indicating that virtually every fireplace backdrafts or spills. Selection of home ventilation strategies is cited as one way to avoid backdrafting.

Data discussion: Information is mostly anecdotal, but it does identify backdrafting as a potential problem if all of the systems are not considered in the home design.

T4. **Builder blunders**, December 2003, JLC

Description/Scope: Describes major problems that have occurred in real homes.

How does this relate to systems approach: The designing of the duct system in one home caused peeling paint on the siding. The main second story supply duct was routed through the exterior wall and a whole-house humidifier was also part of the HVAC system. The operation of the humidifier and the heating system resulted in excessive condensation on the sheathing and siding.

Data discussion: The example is limited to one case identified by the contractor.

T5. **CO Leaks, Causes and Cures**, March 1998, JLC

Description/Scope: Presents three cases of backdrafting and solutions.

How does this relate to systems approach: One of the cases documented building depressurization and subsequent CO poisoning caused by competing vented appliances in a relatively tight home, and insufficient make-up air supply.

Data discussion: Anecdotal, but another confirmation of the interaction between the building envelope tightness and appliance performance.

T6. **Wall details for cooling climates**, May 1995, JLC

Description/Scope: Article describes a home designed by PG&E using a systems approach to resist summer heat gain.

How does this relate to systems approach: Illustrates some of the inter-relationships between various systems and the aesthetics of the home including:

1. Impact of placement, orientation, and amount of windows on energy use
2. Impact of floor plan, especially number of corners and length of exterior walls, on energy use.
3. Roof overhangs to provide summer shading of windows.

Overall, the changes above reduced the estimated energy use by 23% from the original house plan. The also were careful to evaluate the impact of an energy efficient wall system on the structural systems' performance.

Data discussion: This is a good example of how one project team used what they call a systems approach to design a home with certain energy efficiency goals as their primary goal. No detailed data are provided but the sources of the information (Davis Energy Group and PG&E) are respected organizations.

T7. The value in OVE, Housingzone.com, July 1, 2003

Description/Scope: Article describes advanced framing techniques and how several homes were modified to optimize both energy and structural performance.

How does this relate to systems approach: Article describes the relationship between framing and energy performance.

Data discussion: Presents several real live examples of the OVE techniques but no supporting data or references.

T8. Partnering for systems performance, August 1, 2002, Housingzone.com

Description/Scope: Describes the systems approach adopted by a home builder under the Building America program.

How does this relate to systems approach: Theoretically discusses the systems approach, but details on the approach are vague. Describes the need to retrain subs and employees, which suggests that systems design is as much about communication and process as it is about proper design and use of technology or materials.

Data discussion: No supporting data or detailed performance information. Mostly a sales article on systems approach.

T9. Energy Experts, March 3, 2000, Housingzone.com

Description/Scope: Describes practices of winners of the Energy Value Housing Award. All of the builders claim to use a systems approach, describing it mostly as planning for heating and cooling the home from the outset not as an afterthought.

How does this relate to systems approach: Not much on detail, but identifies multiple builders who claim to use a systems approach. The builders could be good case studies for later tasks in this project.

Data discussion: Potential useful names of builders for later tasks, but no real data or systems related information.

T10. **Ventilating attics to minimize icing at eaves**, Home Energy Magazine, April 1995

Description/Scope: Article describes icicle formation and ice dams and how to eliminate or minimize them. Most of the emphasis is on ventilation strategies in larger buildings at Ft. Drum in New York, although application to homes is also discussed.

How does this relate to systems approach: This article connects the formation of ice dams and icicles with design of several subsystems in buildings. Interactions include:

1. A relationship between attic ventilation rate and ice formation. Blockage of vents is an important item to consider. Mechanical attic ventilation is required in very cold climates for larger buildings but natural ventilation is usually acceptable for homes.
2. A relationship between ducts in attics and ice formation. Supply ducts inadvertently heat the attic and can contribute to the problem.
3. A relationship between gutters, roof overhangs and ice formation. They suggest that too small an overhang causes wetting of walls below the roof.

Data discussion: The authors present data to back up most of their findings and conclusions. They also reference reputable organizations such as University of Minnesota who have confirmed similar findings.

T11. **Builders find new technologies paying off**, Home Energy Magazine, February 1999.

Description/Scope: Describes the status of projects under the DOE Building America Program through 1999. Includes some specific techniques, how they worked, and costs in general.

How does this relate to systems approach: Several interactions between systems or subsystems are identified:

1. Drafts around fireplaces can contribute to backdrafting
2. Higher performance windows allowed shorter duct runs
3. Envelope modifications (reduced infiltration, greater insulation levels, and better windows) allowed significant reductions in cooling equipment size.

Data discussion: The article discusses findings from reputable sources involved in a high-profile DoE program. But it does not present data to support the conclusions. An interesting interaction that was not discussed in great detail was between the structure and the thermal envelope. In several of the projects, exterior foam insulation was used in place of OSB or plywood, even with 24 oc spacing of studs. There was no discussion of the potential large negative impact on structural performance due to this practice.

T12. **Perry Bigelow: Energy efficiency maestro.** Home Energy Magazine, April 1994.

Description/Scope: This article is a feature article on the practices of a builder in the Chicago area. The emphasis is on energy efficiency.

How does this relate to systems approach: The main related item is that the builder was able to downsize the HVAC system due to changes to other parts of the home including OVE framing, efficient windows, and tight construction.

Data discussion: This is at best a good case study opportunity. The conclusions are not supported by data, but the information is from reputable sources from the DoE Building America program.

T13. **Saving energy with reflective roof coatings**, Home Energy Magazine, May/June 1994.

Description/Scope: Most of the article describes work conducted to measure the impact of reflective coatings on reflectivity and cooling energy requirements.

How does this relate to systems approach: The interaction between selection of roof type and color is identified. Metal and tile roof products in white or light colors are available, but not for asphalt roofing.

Data discussion: Data is presented that relates energy savings to reflective roof coverings. The authors stretch the findings to include roof color selection in homes.

T14. **Bigger is not better: Sizing air conditioners properly**, Home Energy Magazine, June 1995.

Description/Scope: Describes the different accepted methods for proper sizing of equipment and identifies problems from not doing so.

How does this relate to systems approach: The article is relevant because it identifies the methods used to properly size a cooling system including Manual J (load), S (equipment sizing), and D (duct design) from ACCA. If the interactions between envelop efficiency and equipment sizing are to be realized as benefits, these design tools will need to be used more often in the industry.

Data discussion: Only anecdotal information on interactions is provided. However, the reference materials for equipment sizing are well recognized tools.

T15. **Shade trees as a demand side resource,** Home Energy Magazine, April 1995

Description/Scope: Describes modeling and other studies of the impact on energy use and other benefits from placement of shade trees around homes.

How does this relate to systems approach: Article identifies the interaction between landscaping and energy use in homes.

Data discussion: Some modeling results are discussed and many references to other studies are presented.

T16. Advanced Houses: The Canadian experience, Home Energy Magazine, September/October 1996

Description/Scope: Article describes a ten-home advanced houses program operated by National Resources Canada. The homes are located throughout Canada and use a systems approach to address energy, indoor air quality, window selection, lighting, framing, and construction waste issues.

How does this relate to systems approach: The project identifies 10 potential case studies where we could obtain performance data.   Some of the interactions identified include: the envelope with windows, framing materials with the thermal envelope, and selection of appliances/lighting with the heating system.

Data discussion: The article is a general interest article. Results are discussed but no data or details are provided. The authors represent NRC, which is a reputable organization.

T17. Building Affordable Homes, Fine Homebuilding, February/March 2002

Description/Scope: This article discusses one builder's attempt to use a systems approach to building affordable homes.

How does this relate to systems approach: The builder may be a good case study for systems design. He uses OVE, right sizing of HVAC, and optimization and integration of multiple systems and subsystems in the home. The article also describes the importance of the integration of the subcontractors into the design and planning stages.

Data discussion: The article is only a summary of the builder's practices. No data are presented. Perhaps the most important issue is the non-technical "process" improvements this builder feels are important to his approach.

Other trade articles reviewed but found not applicable:

JLC:

Combining heating and cooling systems, October 1994
Where roofs meet walls, May 1987
Installing high velocity HVAC, July 2003
Installing a heat recovery ventilator, January 2003
Water managed wall systems, March 2003
The business of building green, March 2003
House wrap and air leakage: new studies, December 1993
Resisting the wind, March 1994
Finding hidden heat leaks, August 1992
Finding the flaws in super insulation, August 1987
Common electrical inspection failures, March 2003
Plumbing pitfalls, February 1998
The dirty dozen, common plumbing services calls, October 1994
Common construction defects, October 1998
Misreading a house, September 1987
The Swedish solution, January 1886
Whole house ventilation that works, May 1990
Indoor mold, causes and cures, June 2003
Nine steps to ventilation system design, November 1996

Housingzone.com:

Prototype truss design keeps ducts in building envelopes, August 1, 2002
An energy star is born, October 1, 2001
Business benefits: reduced risk, more sales, better employees, August 1, 2003
John Knott: Holistic development, February 1, 2002
Systems engineered housing, March 1, 2001
Building green in a black and white world. Excerpt from Chapter 1, no date
The environments for living program, impacts home building today, May 23, 2003
Building energy efficient homes, January 31, 2001
Sustainable sites, September 1, 2000
Holistic medicine for existing homes, August 1, 2003
OVE in Brief, July 1, 2003

Builderonline.com:

America's best builders: Sattler homes, January 1, 2003
Backstage, January 24, 2002
Mold block, May 1, 2002

Home Energy Magazine:

Remodeling kitchens, a smorgasbord of energy savings, October 1995
Selecting windows for energy efficiency, August 1995
Integrating heating and ventilation, June 1993

Stories from the buffer zone, October 1993
Sizing air conditioners, if bigger is not better, what is? October 1996
Wrap it up, building houses with the skin on the outside, December 1999
Efficient cooling, making it happen, April 1998
Wisconsin primes the whole house pump, January/February 1999

Attachment B - Scientific/technical literature

STANDARDS

1. A review of the regulatory and technical literature related to crawl space moisture control: (*Rose, W B. ASHRAE Transactions. v 100 n 1 1994. ASHRAE, Atlanta, GA, USA. p 1289-1301.*)
   - Regulations for attic ventilation and crawl space ventilation appeared simultaneously in 1942. An acknowledgement of the possibility of high moisture loads from crawl spaces may have influenced the choice of attic ventilation ratios.
   - Building regulations after 1956 responded by mandating the use of ground covers in crawl spaces. The moisture control effectiveness of ground covers has been established in the literature.
   - The ability of pea gravel topping to affect evaporation rates has not been determined conclusively.
   - Much of the technical literature emphasizes the importance of good construction practices, including maintaining an 18-inch clearance between soil and floor framing, providing easy access to the crawl space, removing debris from the crawl space, and providing good drainage around the house.

2. Energy code measures to assure the effectiveness of thermal insulation installed in buildings: (*Nelson, Bruce D. ASTM Special Technical Publication. Publ by ASTM, Philadelphia, PA, USA. n 116. p 92-99.*)
   - Degradation of insulation performance is caused by air exfiltration and wind wash.
   - U.S. model energy codes do not address wind wash. Buildings constructed under the air leakage requirements of current model energy codes have been found to have significant air leakage problems.
   - Residential Standards Demonstration Program (RSDP), Super Good Cents, and Minnesota Energy Code prescribe measures to reduce exfiltration and wind wash.

3. Integrated energy performance standard for heating systems: (*Zirngibl, J. ASHRAE Transactions. V 108, part 2, 2002, p 926-934*)
   The energy consumption can be reduced significantly if
   - Efficient heating systems are used.
   - The interaction between the building and the heating installation is optimized.

   A reliable method for calculation of the energy performance: CEN TC 228 WG4.
   Standards prEN 14 335 takes into account the losses of emission, distribution, storage, heat generation, and control.

4. R-2000 and advanced houses: the Canadian experience: (*Mayo, Tim. Sinha, Robin. Journal of Thermal Insulation & Building Envelopes. V21 Jul 1997. p 91-111.*)
   - The technology changes occurring in Advanced Houses fall into five major areas:
     - o Designing the house as a system:
     - o Upgrading the building envelope
     - o Integrating the mechanical systems

- Selecting materials and finishes to ensure better indoor air quality
  - Providing environmental features
- More efficient envelopes, different approaches to heating and cooling can be considered – different energy sources, different equipment, and different distribution.
- In addition to energy savings, high-performance windows are highly condensation resistant, thus offering significant maintenance and health benefits by reducing the potential for peeling paint, wood rot, and mold growth. Their warm interior surfaces make occupants feel more comfortable, and eliminate the need for heating outlets beneath the windows.
- High-performance windows and small heat loads mean air-flow volumes can be less. The 2" diameter, high-velocity ducting was originally intended to provide fresh-air ventilation, but also has the capacity to meet the reduced heating and cooling loads. Small-diameter ducting offers significant opportunities for replacing electric baseboard heating and providing ventilation in the renovation market.
- A sealed-combustion, condensing natural gas hot water heater with remote fan-coil units providing space heating through the forced air ductwork system. These combination space/DHW products have a rated efficiency of better than 90 percent.
- For the mid-efficiency natural gas furnace/HRV (heat-recovery ventilators) combination unit, the combined efficiency is expected to be 85 per cent.
- As continuous ventilation becomes more common, the need to integrate improved fan/motor sets into mechanical equipment becomes more important. The energy penalty for running central furnace fans to provide ventilation is simply too high.
- The best technology on the market is the electrically commutated motor (ECM). Used in variable-speed blowers, ECMs maintain the same high efficiency over their entire range of speeds and hold airflow steady at specified levels regardless of changes in static pressure. In a typical furnace installation, they can save almost 60 per cent in electricity consumption.

5. Residential energy (*McQuiston, Faye C. M Emanuel. Busch, Robert D. Taylor, Z Todd. ASHRAE Journal. V 30 n 5 May 1988 p 37-42, 44*)
   - In 1985, Special Project 53 (SP-53) had the responsibility of reviewing existing standards and current residential building construction practices suggesting needed research that could be done in a timely manner, performing some analysis and formulating recommendations for a standard based on their findings.
   - The standard recommendations are intended to be used in all 50 states and for the following types of new residential buildings: single family detached, low-rise multi-family and manufactured (e.g., mobile homes) housing. The recommendations cover the thermal envelope, the heating and cooling system(s) and the domestic hot water system.
   - The discussions outline, for three of the key areas, the direction taken in creating the standard:
     a. Economic analysis
     b. Thermal mass in walls
     c. Foundation analysis

6. The residential ventilation standard: (*EETD News, Lawrence Berkeley National Laboratory. v 2 n 3,Spring 2001 p 6-7.*)

- ASHRAE Standard 62.2P.
- The purpose of ventilation is to provide acceptable indoor air quality.
- Three primary sets of requirements:
  - Whole-house ventilation
  - Local exhaust
  - Source control
- Whole-house ventilation is intended to bring fresh air into the general environment to dilute the pollutants that cannot be effectively controlled at the source.
- Total amount of outside air needed: add 2cfm/100 sq. ft. (10 l/s/100 sq. m.) to the 15cfm/person (7.5 l/s/person). The air change rate requirement will vary by the size of the house and the occupancy.
- Each room has either a window or a local exhaust system
- Air handlers are required to have particulate filters having a minimum efficiency of 60% for 3-micron particles.
- Whole-house fans are quiet (1 sone) and bathroom and kitchen fans are reasonably quiet (1.5 sones) at their rated flows.
- Adequate separation between inlets and exhausts or other known sources of pollution.
- Any air-handling equipment placed in attached workspaces or garages should be sealed to prevent entrainment of these contaminants.
- Clothes dryers should be vented directly to the outdoors both to minimize moisture and laundry pollutions. Clothes dryers are treated as exhaust fans for the purposes of combustion safety and ventilation.
- Naturally aspirated combustion appliances in the conditioned space should pass a specific backdrafting test if the total of the largest two exhaust appliances exceed about 1 air change per hour of ventilation (not counting any summer cooling fans).
- A carbon monoxide alarm should be installed.

STRUCTURE

Concrete:

7. A Habitat of Fiber Reinforced Concrete: (*Zollo, Ronald F. Hays, Carol D. Concrete International. v 16 n 6 Jun 1994. p 23-26.*)
   - Fiber reinforced cellular concrete (FRCC) panels were evaluated suited to residential construction especially where ***wind storm*** and home ***energy conservation*** are important design criteria.
   - Material costs are higher than conventional masonry; savings will be realized in field production labor costs even without consideration of insulating costs.

8. Concrete Floor Systems in Residential Construction: (*VanderWerf, Pieter A. Ridsdale, Cameron. Aberdeen's Concrete Construction. v 42 n 10 Oct 1997 p 798, 800, 802, 804-805.*)
   - Insulating concrete form (ICF) homes

- The cost of a concrete floor is $1 to $3 more per square foot than a wood-frame floor. However, the cost differential narrows or disappears in design with very long spans (over 20 feet).
- Advantages in strength, shallower depths, sound attenuation, thermal mass, fire resistance, and unique finishes.
- Four types:
  - concrete on steel joists
  - concrete on steel deck
  - concrete slab and joist
  - precast concrete

9. Hollow-core Concrete Floors over Basements: (*Hurd, M K. Concrete Construction. v 31 n 10 Oct 1986 p 881, 883.*)
   - The hollow-core precast floor system over basement can span longer, leaving a basement free of posts or walls. This gives the owner maximum flexibility in interior space planning, and saves the builder the cost of steel columns and beam down the center of the basement. Thicker slabs can be used for longer spans if necessary.
   - Holes for electrical and mechanical services can be drilled and cut on site. Wiring for basement ceiling lighting and hot air for heating the ground floor are carried through the cores of the ground floor concrete slab. A vertical supply duct carries hot air to the second floor for distribution by ducts to the various rooms.
   - Provide fire safety and thermal storage properties.

Steel:

10. Behavior of screw connections in residential construction: (*Laboube, R A. Sokol, M A. Journal of Structural Engineering-ASCE. v 128 n 1 Jan 2002. p 115-118.*)
    - Screw pattern did not significantly influence the strength of the connection.
    - The assumption that the connection strength for a multiple screw connection is proportional to the number of screws in the connection pattern was found to be unconservative.
    - The connection strength decreased with decreased spacing of the screws.
    - A stripped screw in a single shear connection did not result in erosion of the connection strength.

11. Framed in steel: dwellings for the new millennium: (*Rautenberg, Carla. Welding Innovation Quarterly. v 16 n 2 1999. p 7-9.*)
    - The popularity of steel-framed housing continues to be greatest in Hawaii and California, where steel's ability to withstand high winds and earthquakes has been a significant selling point.
    - Light gauge steel is used in 3-4 percent of homes currently being built.
    - Fastening productivity is a critical issue for steel at this stage of its market development.
    - It is expected that welding will be fastest and therefore most cost effective for shop panelization of walls and roof trusses.
    - Advantages:

    - Steel floor joists are dimensionally stable, which eliminates the need to cull and crown each member.
    - Steel joists are lighter and will outspan traditional dimensional wood joists of equal size.
    - Steel is cost-competitive with engineered wood.
- Barriers:
    - The higher cost of construction
    - Thermal performance – steel alone conducts heat through the walls more than wood, but with appropriate insulation, steel can exhibit equivalent or better performance.
    - Lack of infrastructure – the fact that carpenters and lumberyards are accustomed to working with wood, not steel.
    - Lack of standards – although this is now being addressed by ASTM.

12. Lateral behavior of plasterboard-clad residential steel frames: (*Gad, Emad F. Chandler, Adrian M. Duffield, Colin F. Stark, Graeme. Journal of Structural Engineering-ASCE. v 125 n 1 Jan 1999. p 32-39.*)
    - A wall with corner return walls, ceiling cornices, and skirting boards has more than three times the lateral capacity of an identical isolated wall panel.
    - The capacity of walls with full boundary conditions is not linearly proportional to wall length. It is dependent on the presence of these boundary conditions.

13. Recent research and developments in cold formed steel framing: (*LaBoube, R A. Yu, W W. Thin-Walled Structures. v 32 n 1-3 Sep-Nov 1998. p 19-39.*)
    - Appropriate design recommendations for the web and chord members of a truss.
    - The influences that the web opening may have on the bending, shear, and web crippling strengths of the member.

Wood:

14. Effect of construction adhesive and joist variability on the deflection behavior of light-frame wood floors: (*Pellicane, Patrick J. Robinson, Geoffrey. Journal of Testing & Evaluation. v 250n 2 Mar 1997. p 163-173.*)
    - The presence of elastomeric construction adhesives (ECA) between joists and sheathing help reduce floor deflections by 6-12% compared using only nailed connections.
    - The greatest increase was found in more flexible (lower stiffness) floors.
    - The ECA had also the effect of reducing the variability of floor behavior.

15. Glued Engineered Wood Products: (*Williamson, Thomas G. Construction Specifier. v 48 n 5 May 1995. 4pp.*)
    APA classifies glued engineered wood into four categories:
    - Structural wood panels: plywood, oriented strand board (OSB), and composite panels
    - Glued laminated timber (glulam)
    - Structural composite lumber (SCL)
    - Prefabricated wood I-joists

16. Performance-based engineering of wood frame housing: fragility analysis methodology: (*Rosowsky, David V. Ellingwood, Bruce R. Journal of Structural Engineering-ASCE. v 128 n 1 Jan 2002. p 32-38.*)
    - The performance of light-frame wood assemblies is affected by load sharing, partially composite action of members and sheathing, and connection behavior.
    - Performance-based design methodology support
        - Improving the durability of the housing stock
        - Reducing losses due to natural hazards.

17. Remedial framing design for joists in residential construction: (*Jalla, Raj. Journal of Architectural Engineering. v 5 n 2 1999. p 57-60.*)
    - Holes and notches on wood joists should be avoided in the first place.
    - If cutting is unavailable, strengthening of the joists at the location of holes and notches and repair are necessary.

SIP:

18. Panel House Demonstrates Building Innovations: (*http://oikos.com/esb/35/demo.html* 1994)

Structural foam core panels: (plywood siding outside, foam insulation in-between, and OSB inside)

- Reduce the amount of framing lumber by 55%.
- 5-10% less wood.
- Thicker panels (6" for the floor, 8" for the walls, and 10" for the roof) help meet the energy goal with little added cost.
- 40% more energy-efficient.
- Air leakage of .07 ACH compared with conventional houses ranging from .25-.50 ACH.
- Reduce labor to build the shell by 30-35%.

19. Prefabricated wall systems and the North American home-building industry: (*Friedman, Avi. Cammalleri, Vince. Building Research & Information. v 21 n 4 Jul-Aug 1993. p 209-215.*)

Cost, craftsmanship, technical performance, durability, flexibility and ease of assembly were analyzed for nine types of prefabricated wall systems.
Three categories:

- Open sheathed panels
- Structural sandwich panels
- Unsheathed structural panels

Miscellaneous:

20. Testing brings the house down: (*Materials World. v 8 n 12 Dec 2000. p 22-23.*)
    - Over-simplified engineering design methods are not good enough to predict how a building will respond under such extreme loads. Using these techniques, a house can be both over-designed in some areas (making it uneconomical) and under-designed in others (making it less safe).

- The CSIRO researchers are developing just such a tool with their whole-house testing facility. The entire house is fully supported by load cells at its base with each unit capable of measuring loads in three directions.
- Combined testing and modeling can also be used to design new and innovative products and to determine optimal locations in the house where they can be most effective.

NATURAL DISASTER

21. Earthquake ductility and overstrength in residential structures (*Gad, E F. Chandler, A M. Duffield. C F. Hutchinson, G L. Structural Engineering & Mechanics. v 8 n 4 1999. p 361-382.*)
    - This paper reviews aspects of current design procedures for seismic design of structures, and specifically examines their relevance to the design of light residential buildings under earthquake loading.

22. Damage due to Northridge earthquake induced movement of landside debris (*Day, Robert W. Poland, Dennis M. Journal of Performance of Constructed Facilities. v 10 n 3 Aug 1996 p 96-108.*)
    - This paper is described as a case study of Northridge Earthquake induced movement of landside debris
    - The estimated earthquake-induced lateral movement of the landside debris, based on the width of observed cracks, is 6-12 mm (0.25-0.5 in.).
    - Associated with the lateral movement of the landside debris, there was differential movement of 102 mm (4.0 in.) of the house foundation and 69 mm (2.7 in.) for the pool
    - The earthquake-induced movement of the landside debris caused severe damage to the house and appurtenant structures
    - The landside debris is surcharged with fill also decreased the stability of the landside debris

23. Performance of single family house foundations during Northridge earthquake (*Day, Robert W. Practice Periodical on Structural Design & Construction. v 1 n 2 May 1996. p 85-88.*)
    - This paper is described typical damage to single-family house foundations caused by the Northridge earthquake.
    - Damages were due to following factors: (1) A lack of shear resistance of the isolated wood posts; (2) a lack of bolts or inadequate bolted condition of the sill plate to the foundation; and (3) the typical older age of this type of foundation.

24. Reliability of light-frame roofs in high-wind regions. I: wind loads (*Rosowsky, Dvaid V. Cheng, Ningqiang. Journal of Structural Engineering-ASCE. v 125 n 7 1999. p 725-733.*)
    - The statistical of wind loads acting on roof structural components in light-frame structures are evaluated for use in a reliability analysis.

25. Reliability of light-frame roofs in high-wind regions. II: reliability analysis (*Rosowsky, Dvaid V. Cheng, Ningqiang. Journal of Structural Engineering-ASCE. v 125 n 7 1999. p 734-739.*)

- There are relatively small number of sheathing panels and roof-to-wall connections that control the overall roof system capacity, and hence dominate the failure probability.
- These critical sheathing panels are located at the edge (usually on the corners) of the roofs, and critical roof-to-wall connections are located at or near the gable end.
- In order to achieve a more balanced design (from the standpoint of probability of failure), it is suggested that these connections nearest to the edge of the roof be attached using a fastener schedule that ensures adequate uplift capacity.

26. Residential construction failures caused by hurricane Andrew (*Suaris, Wimal. Khan, Mohammed S. Journal of Performance of Constructed Facilities. v 9 n 1 1995. p 24-33.*)
    - The failure in masonry construction can mainly be attributed to lack of anchorage because the wall reinforcing was either missing or not hooked to the tie beam
    - Some masonry-wall failure was caused by the tie beam bending about its minor axis when subjected to deficient design and construction practices.
    - Wood end gables were a typical feature in housed in South Florida that failed due to lack of proper bracing.
    - Loss of roof sheathing was common due to inadequate nailing
    - The breach of the exterior building envelope by the loss of roof sheathing and broken windows/doors led to extensive interior damage in most houses.

27. Seismic weakness of some residential wood framed buildings: confirmations form the 1994 Northridge earthquake (*Filiatrault, Andre. Stieda, Chris K A. Canadian Journal of Civil Engineering. v 22 n 2 Apr 1995. p 403-414.*)
    - This paper reviews the various potential weakness of some residential timber framed buildings
    - The following problems should be recognized and urgently addressed to raise the safety of residential wood framed buildings in the active seismic zones of the country
        - Soft stories appeared to be the major contributors to seismic vulnerability and can lead to collapse
        - Failure of structural elements, such as studs or joists, is unlikely to be the primary source of a building collapse.

ENVELOPE

Windows & Door:

28. Low E glass increased performance/greater design freedom: (*Vales, Noel. Construction Specifier. v 41 n 8 Aug 1988 p 73-78.*)
    Low-E glass: positive energy contributor - High-light-transmission, heat-insulating (low-emissive) coatings on glass.

29. Market transformation efforts for residential energy effect windows: an update of national activities: (*Ward, Alecia. Suozzo, Margaret. Eto, Joseph. Proceedings Aceee Summer Study on Energy Efficiency in Buildings. v 2 2000. p 2323-2333.*)

- This paper summarizes how other federally-funded building industry initiatives that emphasize “whole house” performance can complement these window technology-specific and component-specific initiatives.

30. Spectrally selective glazings for residential retrofits in cooling-dominated climates: (*Lee, E S. Hopkins, D. Rubin, M. Arasteh, D. Selkowitz, S. ASHRAE Transactions. v 100 n 1 1994 ASHRAE, Atlanta, GA, USA. p 1097-1114.*)
    - Spectrally selective glazings can reduce energy consumption and peak demand in residences by significantly reducing solar gains with minimal loss of illumination and view.
    - In cooling-dominated climates, solar gains contribute 24-31% to electricity consumption and 40-43% to peak demand in homes with single-pane clear glazing.

Roof:

31. An exchangeable PV shingle: (*Yagiura, T. Morizane, M. Murata, K. Uchihashi, K. Tsuda, S. Nakano, S. Ito, T. Omoto, S. Solar Energy Materials & Solar Cells. v 47 n 1-4 Oct 1997. p 227-233.*)

Compared with previous PV modules
- Lower total cost
- Simple construction and maintenance
- Good design
- Fire resistance

32. Building integrated PV and PV/hybrid products – the PV:BONUS experience: (*Thomas, H.P. and Pierce, L.K. National Renewable Energy Laboratory, Oct 2001. www.nrel.gov/docs/fy02osti/31138.pdf*)
    - Conducted by DOE
    - HeatGuard™ : an interlocking, insulating roof tile that allows only 1% of the thermal insulation into the building.
    - Flexible PV membrane: a roof application
    - Electrochromic windows: with a PV-powered variable control

33. Test and Evaluation of the attic temperature reduction potential of plastic roof shakes: (*Holton, John K. Beggs, Timothy R. ASHRAE Transactions. v 105 (PART 1) 1999. p 858-868.*)
    - The attic air temperature of one house with a plastic shake roof was consistently 20ºF (11ºC) cooler than its twin with asphalt shingles during peak summer cooling periods.
    - The gaps between plastic shake panels and the void space underneath would appear to provide good pathways for convective airflow and heat transfer.

34. US PV: BONUS (*Thomas, H.P. and Pierce, L.K. National Renewable Energy Laboratory, Oct 2001. www.nrel.gov/docs/fy02osti/31138.pdf*)
    - Flexible lightweight roofing materials
    - Dispatchable peak-shaving systems
    - Home manufactured with PV
    - AC modules
    - Architectural PV glazing systems, Advanced Photovoltaic Systems (APS)

35. Updates on revision to ASHRAE standards 90.2: including roof reflectivity for residential Buildings: (*Akbari, H. Konopacki, S. Parker, D. Proceedings Aceee Summer Study on Energy Efficiency in Buildings. v 1 2000 p 11-111.*)
    In hot climates, increasing the roof reflectivity from 20% to 60% is worth over half of insulation.

Wall:

36. Mapping of air leakage in exterior wall assembly: (*Desmarais, Guylaine. Derome, Dominique. Fazio, Paul. Proceedings of the Spe/Isrm Rock Mechanics in Petroleum Engineering Conference Journal of Thermal Envelope & Building Science. V 24 n 2 Oct 2000. p 132-154.*)
    - The added rigid insulation may have helped to reduce the amount of air leakage into the assembly.
    - When rigid insulation was installed on the warm side of the batt insulation, moisture accumulation was lower.

37. Wood frame walls in cold climate – vapor barrier requirements: (*Thue, Jan Vincent. Skogstad, Hans Boye. Homb, Anders, Journal of Thermal Insulation & Building Envelopes. v 20 Jul 1996. p 63-75.*)
    - Both the diffusion resistance at the warm side and the ratio between diffusion resistance at warm and cold sides have to be considered when designing wood frame walls in cold climates.
    - The diffusion resistance of the warm side should be above some limit value.
    - A high ratio between diffusion resistances at warm and cold sides may, to some extent, compensate for a low resistance at the warm side.
    - Increasing the insulation thickness will reduce heat transmission and thus enhance the requirements to the barrier layers in the wall, especially the ability to dry out occasionally condensed moisture.
    - A traditional structure with a PE-foil (0.15mm) on the warm side can be considered "moisture safe" if it has no air leakage. (in cold climates)

Insulation:

38. Basement Insulation Systems: (*Yost, N.;Lstiburek, J. Posted on this site with permission from Building Science Consortium. 20 pp. 2002*)
    - Basement walls with insulation on the exterior perform better than basement walls with insulation on the interior. However, it is rarely installed due to:
        - Difficulties protecting it from damage during backfilling
        - Protecting the above grade portion of the exterior insulation is expensive
    - Interior stud wall framing insulated with fiberglass batts and "blanket" insulation are unsuitable for use due to serious problems associated with mold, decay, and odors.
    - All recommended basement interior insulation strategies involve placement of rigid foam insulation against the foundation wall.
    - Heat loss from an uninsulated basement accounts for up to 1/3 of the heating cost in an average home (Timusk, 1981).

- Heat loss through uninsulated above grade basement walls accounts for up to 30% of the total heat loss from the basement (Timusk, 1981).
- Many researchers recommend water proofing as superior to damp-proofing for controlling moisture in basement walls.
- For a basement in a 4,000 heating degree-day location
  - Insulating the upper half of the basement wall with R-5 insulation reduces the heat loss from the basement by approximately 50%
  - Full height insulation reduces heat loss from the basement by approximately 70%
  - Insulating the exterior wall to grade and the upper half of the interior wall results in approximately 10% more heat loss than full height insulation on either the interior or the exterior.
- Proprietary insulated pre-cast concrete wall

39. Cold climate foundation insulation retrofit performance: (*Robinson, D A. Shen, L S. Goldberg, L F. Nelson, G D. Hewett, M J. Noble, M T. ASHRAE Transactions. Publ by ASHRAE, Atlanta, GA. USA. v 96 Pt 2. p 573-579.*)
    - Average basement temperatures increased by 4.6ºF and 4.0ºF for houses receiving interior and exterior retrofits. In addition to greater basement comfort levels, a greater level of comfort throughout the rest of the house is reported.
    - Insulation applied in an uncontrolled zone produces highly variable results and has the principal effect of increasing the temperature and comfort of the basement rather than producing cost-effective whole-house energy savings.

40. Insulation: (*Oak Ridge National Laboratory. Posted on this site with permission from Oak Ridge National Laboratory. 24 pp. 2002*)
    - Insulate the attic to the recommended level, including the attic door, or heat cover
    - Provide the recommended level of insulation under floors above unheated spaces, around walls in a heated basement or unventilated crawl space, and on the edges of slabs-on-grade.
    - Use the recommended levels of insulation for exterior walls for new house construction.
    - Insulation can also act as a sound absorber or barrier, keeping noise levels down.
    - A computer program "ZIP-Code" is available to help calculate the amount of insulation appropriate for the house. http://www.ornl.gov/roofs+walls
    - If water lines and the ducts of heating or air-conditioning system run through unheated or uncooled spaces, such as attic or crawl spaces, then the water lines and the ducts should be insulated.
    - Return air ducts located inside the heated portion of the house should be sealed off from air passageways that connect to unheated areas. Drywall-to-ductwork connections should be inspected to prevent unwanted air flows through wall cavities.

41. Insulation failure and moisture problems resulting from inadequate installation of insulation and/or vapor retarders: (*Sherman, M H. Dickerhoff, D J. ASHRAE Transactions. v 104 n 2 1998. ASHRAE, Atlanta, GA, USA. p 1368-1372.*)
    - Foil backed gypsum panels and residential batt facers are not vapor barriers in a building wall or ceiling as there is no known way to seal the joints.

- The ordinary batt facers are quite combustible as well as ineffective as an air barrier or vapor retarder.
- Foam insulations must have separate vapor retarders to function reliably in most applications.
- Recessed lights frequently result in compromised ceiling insulation system performance. One solution is foil-faced foam board, at least 1.5 in. (0.04 m) thick, fabricated into five-sided boxes sealed over the recessed lights.
- Tapping the roof sheathing joints under the insulation to obtain an air barrier.
- In hot, humid geographic area, the warm side air/vapor retarder is on the exterior of the building. In the attics the barrier must be on the top of the insulation and sealed to the wall vapor retarder. Homes constructed of concrete block masonry walls, a moisture-resistant foam insulation with taped joints or a low permeability (to water vapor) coating on the stucco is required.

42. Superinsulated Houses: (*Shurcliff, William A. Annual Review of Energy. v 11 1986 p 1-24.*)
    - Superinsulation is a direct response to the fast-rising cost of home heating. Of the many kinds of responses, superinsulation is proving to be the simplest and most cost-effective.
    - Superinsulation provides a high degree of comfort in winter and summer, reduces fuel consumption by 75-95% relative to conventional houses, allows the architect great flexibility of house design, and increase construction costs by 10%~ 0%.
    - A superinsulated house is one that a) receives only a modest amount of solar energy (south-facing window area <= 8% of floor area) b) well-insulated and airtight. Auxiliary heat is needed < 15%.
    - Employing much thicker insulation on the attic floor, in the exterior walls and basement walls, beneath the basement floor/entire slab or along the slab periphery only, well-insulated exterior doors.
    - Prevention of moisture migration
    - Greatly increasing air-tightness
    - Placing a large proportion of the window area on the south side of the house
    - Wintertime indoor-air RH should be in the neighborhood of 35-60%. In extremely cold weather the RH should not greatly exceed 40%.

43. Substrate barrier effects for an R-19 fibrous insulation batt: (*Harris, K T. McCarty, T A. Roux, J A. Journal of Thermal Insulation & Building Envelopes. v 19 Jul 1995. p 28-48.*)
    - Heat transport in ceiling insulation is assumed to be transferred by three mechanisms: conduction, radiation heat transfer, and moisture transport (convection not considered).
    - The addition of a plastic vapor barrier at the substrate reduced the total heat transfer by 13% when compared to a no vapor barrier case.
    - With the addition of either a perforated or non-perforated radiant barrier at the substrate, the total heat transfer essentially did not change when compared to the no vapor barrier and plastic vapor barrier cases, respectively.
    - The combination of a vapor barrier to the substrate and a radiant foil barrier above the fiberglass insulation resulted in a total heat transfer reduction of 53% (experimental data), when compared to a standard R-19 insulation batt.

Miscellaneous:

44. Airtightness of U.S. Dwellings: (*Sherman, M H. Dickerhoff, D J. ASHRAE Transactions. v 104 n 2 1998. ASHRAE, Atlanta, GA, USA. p 1359-1367.*)
    - Multi-story houses leak 11% more (i.e., NL=1.8) than single-story houses (i.e., NL=1.6) with an error of the mean near 1%.
    - Those dwellings that had floor leakage to outdoors (i.e. crawl space homes and unconditioned basement) were slightly tighter (at NL=1.64) than those that had no floor leakage to outdoor (i.e. slab-on-grade and fully conditioned basement homes) (at NL=1.75).
    - The homes with duct systems were tighter (NL=0.7) than those homes without duct systems (NL=0.9).
    - NL: normalized leakage.

ENERGY

Design:

45. Barriers to implementing energy conscious design in housing (*O'Riordan, Joan P. Migan, Josep C. Proc. Of the Natl Passive Sol Conf. 4th, Kansas City, MO, Oct 3-5 1979 Publ by Intl Sol Energy Soc, Inc, Am Sect, University of Del, Newark, 1979 p 10-14.*)
    - Energy conscious design is defined as a combination of energy conservation measures and solar tempering, which optimized within a specific microclimate, dramatically decreases the total generated energy requirements of a building or group of buildings.

    Energy-10 (NREL, *http://www.nrel.gov/buildings/energy10/whatis.html*)
    - Energy-10 integrates daylighting, passive solar heating, and low-energy cooling systems with energy-efficient shell design and mechanical equipment.
    - It enables designers to make decisions about energy efficiency early in the design process.

46. Evaluation of EnergyGuage USA®, a Residential Energy Design Software, Against Monitored Data (*Fuehrlein, Brian S. Chandra, Subrato. Beal, David. Parker, Danny S. Vieira, Robin K. Proceedings Aceee Summer Study on Energy Efficiency in Buildings. v 2 2000. p 2115-2126.*)
    - EnergyGuage USA® is being developed for calculation of energy use in residential buildings.
    - EnergyGuage USA® software was accurate predicting energy consumption in entry level homes.

47. Residential energy design (*Dorgan, Charles E. (Univ of Wis-Ext, Madison) Proc of the Annu UMR-DNR (Univ of Mo-Rolla/Mo Dep of Nat Resour) Conf on Energy, 4th, Univ of Mo-Rolla, Oct 11-13 1977 Publ by Univ of Mo-Rolla, Ext Div, 1978 p 393-401.*)
    - Energy checklist - it is important that all items in this list be coordinated to insure the best options are selected:

- Thermal Enclosure
- Site
- Housing design
- Energy heating/cooling system
- Ventilation/Infiltration
- Appliance
- Others

- A substantial reduction in the energy required for homes can be accomplished with only a minor increase in cost for new construction
- The key parameters are:
  1) Assistance in the design to insure maximum use of the additional cost
  2) A willingness to change some traditional plans and room use
  3) Be wiling to take some risk on new construction details and layouts
  4) A design that is able to accept future energy systems

48. Some problems associated with the design of low energy housing (*Warren, Brian Frederick (The university, Newcastle upon Tyne, Engl); Wiltshire, Thomas John. Energy and Housing, Symp, Proc Open Univ, Milton Keynes, Engl, Oct 31 1974 p 105-118. Publ by Pergamon Press (Build Sci: Spec Suppl), Elmsford, NY, 1975.*)
    - High standards of insulation results in a shift in emphasis; of the relative importance are those relating to ventilation control, control of heating systems, and the effects of miscellaneous energy inputs which, in theory, are area of high energy saving potential.

Energy Conservation:

49. Are window energy performance selection requirements in line with product design in heating-dominated climates? (*Henry, R Dubrous, F. ASHRAE Transactions. V104 n 2 1998 ASHRAE, Atlanta, GA, USA. P. 799-805.*)
    - Energy efficiency criteria for selecting windows and the limitations imposed be the necessity of a factory rating number as opposed to using specific design criteria for each house window
    - Energy Rating (ER) concept
      ER = +solar gains –transmission loss –infiltration loss
    - Energy performance considerations suggest minimizing window areas since this part of the building envelope is subjected to greater heat transmission than reasonably insulated walls and roofs

50. Best practice upgrades for energy efficient new homes (*Meisegeier, David. Chinery, Glenn. Proceeding Acess Summer Study on Energy Efficient in Buildings. v 1 2000. p 1187-1196.*)
    - Builder Option Packages (BOPs) are currently used as marketing tools to communicate the typical energy efficiency features of EERGY STAR homes in each five climate regions of the U.S.
    - Energy Star home program uses the Home Energy Rating System (HERS) methodology for determining an energy score for the home.

51. Building and marketing energy conserving homes in 1980 (*Himes, William B.; McGowan, Thomas F., Rockett, Luann T. Int J Hous Sci Appl v 5 n 2 1981 p95-101.*)
    - Recent experiments in constructing energy conserving homes have found 50 to 70% reduction in energy usage easily achievable, while adding less than 30% to the selling price of the house as following three key elements:
        - Adequate insulation, properly installed
        - Reduced air infiltration
        - Proper sizing and installation of heating and cooling system
    - Each portion of the load (walls, floors, glazing, etc) is examined by adding insulation, storm windows, etc.
    - An oversized heating or cooling unit costs more to purchase, costs more to operate, wastes more energy, and produces less comfort.
    - Use alternative energy sources as like that the installation of a wood stove can be from 40% to 60% efficient for supplement space heating

52. Energy consumption in residential structures (*Harvey, D.G. Hittman Assoc, Inc, Columbia , Md; Leighton G. Symp on Energy Econ in Build Des, Speakers' Texts, San Francisco, Calif, Feb 27 1974 19p. Available from Pac Gas and Electr Co, San Francisco, Calif, 1974*)
    - A methodology was developed for analyzing total annual energy requirement of a single-family residence

53. Energy efficiency in existing homes (*NAHB Research Center, U.S Department of Housing and Urban Development June, 2002 www.pathnet.org.*)
    - This document focuses specially on improving energy efficiency in existing housing.
    - It describes the challenges, and outlines activities and accomplishments that will lead to the achievement of the vision.
    - These include promoting new technologies, evaluating products and process for retrofit, building capabilities among trade contractors, and identifying potential consumer incentives.

54. Heat loss characteristics of the ELCAP residential sample (*Pratt, R G. Conner, C C. Lortz, V B. Energy & Buildings. v 19 n 3 1993. p 207-213*)
    - This paper is analyzed heat loss characteristics of the End-Use Load and Consumer Assessment Program (ELCAP) samples of residential buildings and compare these results in a regional context with two objectives, which are to determine the distribution of insulation levels and heat loss potential among the various building components in existing homes as a function of construction vintage and climate zone, and to calculate theoretical residential heat loss potentials for use in subsequent analyses
    - The steady-heat loss coefficient (UA) is the common measure of the heat loss potential of residences, expressing the rate of heat loss through the building shell per degree of indoor/outdoor temperature difference
    - Home insulation levels in the Pacific Northwest are primarily related to vintage rather than climate severity, at both the whole house and component levels
    - The general trend toward vintage as a determinant of thermal integrity of residences could be the consequence of a lack of climatically appropriate energy standards.

55. Low Energy Building Design (*Croome, D. J. and Parker, K. J. IEE conf publ n 186, Int Conf on Eff Use of Electr in Building, London, Engl, Apr 29-May 2 1980. Publ by IEE, London, Engl, 1980 p164-175.*)

- Piped Energy: the choice of effective fuel; effective costs depend not only on source but also on conversion efficiency
- Ambient Energy: average annual net energy consumption wildly depending on the climate
- Solar heat: The daily mean solar radiation (kWh/m^2) is multiplied by the area of the collector panels and corrections made for both the efficiency of the collector and a utilization factor such as south facing sloping roof
- Waste hot water heat: 2500 kWh per year at the tap, and 1250 kWh per year is worth recovering when the net space heating requirements of the house are 4000 kWh per year and perhaps even on hot water heat requirements alone.
- Combined heat and power: about 10% of the national primary energy consumption could be saved
- Heat pumps: make effective use of the heat in the air or the water in the vicinity, and save about 7% of the national primary energy
- Low energy building: The effective use of ambient energy mainly form the sun and free heat from people, cooking, lighting and waste hot water depends on the energy consumption of a building being significantly reduced.
- Passive environmental control: the building rather than equipment primarily controls the environment.
- Hollow block ventilated floor: Outside air is passed down a hollow block floor so that the external daily temperature curve is attenuated by the mass of the floor to give a comfortable supply temperature. Background heat may need to be supplied in winter.
- Airvent window: Heating and cooling loads are reduced by letting an airstream (10-20 l/s per m width) pass between two glass panes.
- Thermic control: Structure can be designed to behave like thermic diode valves. By sandwiching a thick storage layer between two layers of high thermal resistance, and using water to separate the layers, heat can be conducted from one outer layer to the other outer one, or alternatively can be stored in the sandwich.
- Low Energy house design
    - Emphasize passive environmental control; minimize the use of active system; use the energy balance equation to evaluate the balance of materials needed for climate and building type.
    - Utilize as much of the building for collecting, distributing, and storing energy as is practically possible.
    - Select building materials and construction with insulation and thermal response as important factors; distribute high mass storage walls, floors, and internal walls appropriately.
    - Link active system design with passive control system; consider heat pumps and combined heat power scheme where possible; evaluate response of convective and radiant methods of heating spaces
    - Orientate building between SE and SW; loss in solar efficiency within 8% of south facing building

56. Low energy consumption in Swedish single-family houses (*Renewable Energy, v5 Part II, 1994, p 997-999.*)
  - Almost 100% of newly built single-family houses are equipped with mechanical ventilation
  - The most efficient way of reducing the ventilation loss, is to use an exhaust air heat pump which recovers energy from the exhaust air and supplies it to heating and hot water.
  - The ventilation demand is 0.35 l/s per m^2 ventilation floor area which gives about 0.5 air changes per hour and in bedrooms must have an outdoor air flow of 4 l/s per person
  - The exhaust air flow from toilet, bathroom, washroom and kitchen must be 10 l/s for every room
  - If the floor area (except for the kitchen) is more than 10 m^2, it is had to add 1 $l/(s \cdot m^2)$ for the additional area
  - The air flow velocity may not exceed 0.15 m/s in the occupied area
  - The demand of reducing the energy losses by an amount equivalent to 50% of the ventilation losses, can be fulfilled using an extra insulation, but it is more common to recover energy from exhaust air

57. Manufactured housing embraces Energy Star (*Technologies, v 3 n 1, 2003*)
  - This article is explained what Energy Star is and the benefit of this program.

58. Measures used to lower building energy consumption and their cost effectiveness (*Florides, G A. Tassou, S A. Kalogirou, S A. Wrobel, L C. ELSEVIER, 6 Oct 2002*)
  - Ventilation
    - In summer, ventilation leads to a maximum reduction of annual cooling load of 7.7% for maintaining the house at 25 ˚C, and the effect depends on the construction type with the better-insulated house saving a higher percentage
  - Windows
    - Window gains are an important factor and significant savings can result when low conductance and low transmittance window gazing is used, and a saving in the annual cooling load of between 3050 and 5000 kWh can result.
    - The savings in annual cooling load for a well-insulated house may be as much as 24% when low-emissive double glazing windows are used.
  - Overhangs
    - Overhangs can result in savings of the 2000-3000 kWh/year
    - Overhangs may have a length over window of 1.5 m, and in this way, about 7% of the annual cooling load can be saved for a house constructed from single walls with no roof insulation.
    - These savings are about 19% for a house constructed with walls and roof both having 50 mm insulation
  - Shapes
    - The shape of the building affects the thermal loads
    - The elongated house shows an increase in the annual heating load, which is between 8.2 and 26.7% depending on construction type
    - Referring to the orientation, the best position for a symmetrical house is face to the four cardinal points and for an elongated house to have its long side facing south in order to minimize the east wall area that has the biggest load contribution
  - Roofs

    - The roof is the most important structural element of the buildings in the Cypriot environment
    - The roof must offer a discharge time of 6 h or more and have a thermal conductivity of less than 0.48 W/mK in order to keep the loads to a minimum
- Lifecycle cost
    - The increase of the roof insulation pays back in a short period of time, of between 3.5 and 5 years.
    - The increase of the wall insulation pay back after a long period of time, 10 years
    - Low-emissive double-glazing results in a short pay back period of 3-4 years
- This study uses the TRNSYS computer program, for the modeling and simulation of the energy flows of modern houses

59. Potential contribution of the energy-efficient house to system load-factor improvement (*Hammersley, Colin. Power Engineering Journal. v 4 n 1 Jan 1990 p 29-36*)
    - This paper primarily discussed the following practices:
        - Minimizing heat loss through the building fabric
        - Prevention of heat loss through draughts and air leakages
        - Recovering the maximum practicable level of heat from the outgoing warm air
        - Using low-tariff off pick electricity for all space and hot-water heating

60. Thermal performance analysis of a high-mass residential building (*Smith, M. Torcellini, P. A. Hayter, S. J. Judkoff, R. Prepared for the American Solar Energy Society (ASES) Forum 2001, 21-25 April 2001, Washington, DC 2001 8 pp.*)
    - Minimizing energy consumption in residential buildings using passive solar strategies almost always calls for the efficient use of massive building materials combined with solar gain control and adequate insulation.
    - Orientation, overhang dimensions, insulation amounts, window characteristics and other strategies were analyzed to optimize performance in the Pueblo, Colorado, climate
    - In this climate, incorporating massive building materials is an effective strategy for ensuring smaller diurnal indoor temperature swings in low-energy residential building designs.

61. The energy cost of the construction and habitation of timber frame housing (Herman, P.R., 1975)
    - The use of timber framing for external walls, separating walls in relation to semi-detached or terrace type housing and compartment walls of flats and maisonettes, offers energy savings in terms of materials' production of 30% or more, dependent upon the alternatives considered.

62. Wisconsin energy star home program: providing building trades with solutions to cold climate building problems and recognition for high performance homes (*Meunier, Mary G. Caroll, Edward M. Nagan, Joseph P. Proceedings Aceee Summer Study on Energy Efficiency in Buildings. v 2 2000. p 2187-2200.*)
    - This paper introduced the Wisconsin energy star home program and how they approach energy efficiency in new home construction

Solar System:

63. Evolution of a passive solar housing prototype (Reeder, B.C., Merkezas, C.)
- This paper explains the design and development of a prototype for a single-family passive solar house in the mid-Atlantic region of the U.S.
- In concept, the prototype is a highly insulated box, framed conventionally with prefabricated roof trusses which overhang to the south… an east-west extrusion.

64. Passive solar house performance: Derivation from simulation results (*Newton, M N. Warren, B F. Building Sevices Engineering Research & Technology. V 16 n 2 1995. p 91-96*)
- In this paper, the author investigated the thermal performance of forty-three different house designs, incorporating passive solar features, and simulated them for comparison with the simulated performance of selected 'reference' and 'upgraded reference' houses.
- The greatest energy savings are made with the best insulated designs, but at the expense of any useful 'passive solar' contribution.
- Of the 37 designs considered and compared with a developer's house insulated to the same specification and with similar orientation, only 17 (46%) of the upgraded reference achieved savings in auxiliary heating. Four of these designs (11%) achieved a saving solely because of their lower specific heat loss and eight (22%) on account of 'passive solar' measures.

65. Solar Townhouse analysis and design (*Chiang, Robert N. S. (VT); Leland Sangone Chen; Fotis, Charles Willams Jr. Int J Hous Sci Appl v 5 n 1 1981 p 3-25*)
- This paper was written to examine the basic solar energy system's application to townhouse design.
- It attempts to outline an analysis of passive solar systems, its design methods, system integration, guidelines, design process cost, potential options and the appropriate active solar system utilization.

Miscellaneous:

66. A database of window annual energy use in typical North American single-family houses (*Arasteh, D. K., Huang, J. and Mitchell, R. D. ASHRAE, 2000, winter meeting.*)
- This paper developed a database on annual energy impacts of windows in a typical new; single-family, single-story residence in various U.S and Canadian climates.
- The result is a database of space heating and space cooling energies for 13 typical windows and one hypothetical window in 52 North American climates.

67. Building energy monitoring and analysis (BEMA) (*Spears, John W. Publ by American Solar Energy Soc Inc, Boulder, CO, USA. p 476-480.*)
- Building Load Coefficient (BLC) is expressed in Btu/ft^2 of floor area delivered to the conditioned space by the space heating system plus internal gains in Btu, divided by the square footage of conditioned floor area in the house, divided by the difference between the average outside temperature and the average indoor temperature, times 24.
- Doing a simple air infiltration measurement using the AIMS system,

- Component performance analysis iused the energy balance method that assumes energy in is equal to energy out. By using the measured BLC, it calculates the energy out or heat loss rate of the building.
- The delivered efficiency of the HVAC system is determined by dividing the energy delivered to the HVAC system (Btu of oil, gas, electricity) into the actual building load as measured during the co-heating test.
- The contribution of passive solar systems: the assumption is that if the building load is known, it can be measured by the energy delivered through HVAC system and internal gains, then the difference between the energy out (building load) and the energy in (HVAC + internal gains).

68. Effects of house thermal envelope construction conservation features on cooling loads (*Zehr, Floyd J. Publ by American Solar Energy Soc Inc, Boulder, CO, USA. p 704-709.*)
    - This paper employed computer analysis techniques to determine the space cooling loads, along with space heating loads, for various home thermal envelopes in a number of cities.
    - Applying rigid polystyrene insulation to the external basement wall instead of floor insulation, providing greater ground coupling, did reduce the cooling loads somewhat but quite dramatically increased the heating loads with a net tendency to increase the total loads—sometimes significantly, particularly for colder cities.

69. Energy to build (Haseltine B.A., 1974)
    - This paper discusses the capital energy requirements of buildings.

70. Monitoring Energy consumption in single-family houses (*Westergren, Karl-Erik. Hogberg, Hans. Norlen, Urban. Energy & Buildings. v 29 n 3 Mar 1999. p 247-257.*)
    - This paper describes that recently developed Internet-based communication techniques are used to monitor building energy end-use at short time-intervals.
    - Measured energy use from a random sample of homes is standardized for each investigated house by (i) statistically regressing energy data against climate data and (ii) using climate data for a 'normal' year together with the obtained regression equation to determine average annual energy use.

71. Thermal comfort (O' Sullivan, 1975)
    - This paper discusses possible ways in which buildings provide protection from the climate and then goes on to consider the problem of flexibility in thermal comfort

MECHANICAL

72. Analysis on improvement of residential building performance by multizone thermal and airflow model (*Yoshino, H. Hasegawa, F. Nagatomo, M. Ishikawa, Y. Toyohara, N. ASHRAE Transactions. Publ by ASHRAE, Atlanta, GA, USA. V99 pt 2 1993. p 721-729.*)
    - This paper discusses factors which affect the indoor environment of residential buildings in Japan.

- It investigates two calculation models for 10 rooms under 22 different conditions by computer simulation: a thermal model including calculation of room temperature and space-heating loads; an airflow model that calculates multizone air infiltration.
- Improvement of the thermal insulation level for the envelope is most effective for a room temperature rise in rooms without heating and energy saving for space heating.

73. A study of a polymer-based radiative cooling system (*Meir, M G. Rekstad, J B. LOvvik, O M. Solar Energy. v 73 n 6 December 2002. p 403-417.*)
    - This paper investigated and evaluated an alternative cooling system which is a radiative cooling system consisting of unglazed flat plate radiators, using water as a heat carrier while also containing a reservoir.

74. Attic Ventilation Design Strategies for Manufactured Homes (*U.S. Dept. of Housing & Urban Development, Manufactured Housing Research Alliance. http://www.research-alliance.org/media/reports/attic_vent.pdf*)
    - Ventilation of attic and cathedral ceiling air cavities are recommended building practices: moisture control, energy conservation, asphalt shingle durability, and ice dam prevention.
    - For a manufactured home, the air space can be broadly segregated into three regions: the living space, the attic cavity, and the crawlspace (attic is the space between the ceiling and the roof).
    - Attic design in manufactured homes should not be a one-size-fits-all solution and must be examined individually for each climate type.
    - This research is provided the matrix of attic design options-with recommendations of several authors as distilled from the literature

75. Automatic Door opener (*Chan, Pik-Yiu. Enderle, John D. Bioengineering, Proceedings of the Northeast Conference 2000. IEEE, Piscataway, NJ, USA. p 139-140.*)
    - Automatic door opener is designed to pneumatically open or close a door by remote control using radio frequency communication technology.

76. Comparative Ventilation System Tests in a Mixed Climate (*Holton, J. K., Beggs, T. R., ASHRAE Transactions, v 106 Part 2, 2000, p 692-708.*)
    - A lab house constructed in Pittsburgh has been used as a site for the comparative evaluation of ventilation systems: (1) supply fan, (2) exhaust system, (3) heat recovery ventilator, (4) balanced flow fan, and (5) open pipe to the RA plenum by short-term energy monitoring (STEM).

77. Delivering tons to register: Energy efficient design and operation of residential cooling systems (*Siegel, Jeffrey. Walker, Iain. Sherman, Max. Proceeding Aceee Summer Study on Energy Efficiency in Buildings. v 1 2000. p 1295-1306.*)
    - This paper examined a recent innovation in bringing the HVAC system inside the thermal and air leakage envelope by locating the system in a cathedralized attic that is insulated and sealed at the roofline and is well connected to the house
    - Results indicated that cathedralizing (sealing the attic and insulating the roof) is a practical way to improve air conditioning performance in the hot dry climate typical California and the southwestern United States.

78. Domestic kitchen exhaust system: performance assessment (*Riffat, SB. Building Services Engineering Research & Technology. v 12 n 1 1991 p 45-48.*)
    - The effects of a wall-mounted hood and a kitchen extract fan on airflow rates in the kitchen and living-space of a house were examined
    - The air change rates in the kitchen were found to be 2.74, 3.21 and 4.34 h^{-1} when the wall-mounted hood was running at speeds 1, 2 and 3, respectively.
    - The air change rate was 4.4 h^{-1} when the kitchen extract fan was in operation
    - Interzone airflow rate measurements between the kitchen an living space indicated that the use of the kitchen extract fan or wall-mounted hood was ineffective in preventing the movements of moisture and cooking contaminants form the kitchen to living space

79. Effects of radiant barriers and attic ventilation on residential attics and attic duct systems: new tools for measuring and modeling (*Petrie, T. W., Wilkes, K. E., Childs, P. W., and Christian, J. E. ASHRAE Transactions, v 104 Part II, 1998, p 1175-1192.*)
    - A simple duct system was installed in an attic test module for a large-scale climate simulator with a mild winter and a severe summer condition.
    - At the mild winter condition, compared measurements with no radiant barrier attached to the underside of the deck but the ducts installed, there was an average 37% increase in heat loss into the attic with the radiant barriers and ducts in place.
    - At the severe summer condition, the radiant barriers decreased the heat gain through the ceiling, and the average cooling benefit was 34% with ducts in the attic and 29% without them.

80. Implementing of comfort-based air-handling unit control algorithms (*Tse, Wai L. So, Albert T P. ASHRAE Transactions. v 106 Pt1, 2000. ASHRAE, Atlanta, GA, USA. P 29-44.*)
    - Predicted mean vote (PMV) value has been integrated as the major control parameter in the control algorithms with a standard air-handling unit (AHU).

81. Measurement of ventilation and interzonal distribution in single-family homes (*Rudd, Armin F. Lstiburek, Joseph W. ASHRAE Transactions. v 106 Pt2, 2000. p 709-718.)*
    - Ventilation air change rate, local mean age-of-air, and interzonal ventilation air distribution were measured for two single-family homes, located in Las Vegas and Minneapolis, and eight ventilation systems.
    - This paper provided the matrix table of the advantages and disadvantages of ventilation systems.
    - For the Las Vegas house, the periodically operated central-fan-integrated supply ventilation system showed excellent uniformity of ventilation air distribution.
    - For the house in Minneapolis, as long as there was periodic whole-house mixing provided by the central air distribution system, all ventilation systems provided adequate air exchange and ventilation air distribution.

82. Passive stack ventilation: a viable alternative (*Anonymous. H&V Engineer. v 67 n 724 1994. 2pp.*)
    - An extract fan running for only an hour or two per day in a fairy warm dry house will be more energy efficient than passive stack ventilation (PSV): but in a relatively cold house

where a great deal of moisture is also produced, fans will need to run for several hours a day, and mechanical extract ventilation becomes less efficient due to the use of electricity

83. System interaction in forced-air heating and cooling systems, part I: Equipment efficiency factors (*Gu, l. X., Swami, M. V., and Fairrey, P. W. ASHRAE Transactions. V 109 Part 1 2003. p 475-484.*)
    - η_{dist} = DE * Fequip * Fload
    - η_{dist} is distribution efficiency, defined as the ratio of input energy required to meet the heating/cooling load
    - DE is delivery effectiveness, defined as the ratio of heat/cooling output from the ducts to heat/cooling input into ducts
    - Fequip is equipment efficiency factors, defined as the ratio of equipment efficiency in the system
    - Fload is load factor, defined as the ratio of heating/cooling load
    - This equation is used in Standard 152P (ASHRAE)
    - Equipment efficiency factors (Fequip) in Standard 152P is 1.0, but actually Fequip is 1.02.
    - Climate range should be considered to establish a more general regression equation

84. The impact of glazing selection on residential duct design and comfort (*Hawthorne, Wendy A. Reilly, Susan. ASHRAE Transactions. v 106 Part 1, 2000. ASHRAE, Atlanta, GA, USA. p 553-561.*)
    - Heated air must be delivered at the buildings' perimeter in order to control the load and deliver comfort at the windows
    - Predicted mean vote (PMV) is the average value of thermal discomfort and a function of air temperature, mean radiant temperature, relative humidity, air velocity, and the clothing and metabolic rate of the room occupant.
    - PMV and the associated Predicted Percentage Dissatisfied (PPD) were calculated using the modified computer program.
    - After testing and analysis, perimeter duct distribution is unnecessary when the building thermal envelope, particularly the windows, meet specified levels of energy efficiency for a given climate.

85. Thermal comfort assessment of conventional and high-velocity distribution systems for cooling season (*Baskin, Evelyn. Vineyard, Edward A. ASHRAE Transactions. v 109 PART 1 2003. p 513-519.*)
    - Field measurements were taken to determine the thermal comfort conditions using conventional forced-air and high-velocity distribution systems
    - The higher-velocity system delivers higher airflow rate and is projected to remove more moisture than a conventional system
    - The higher-velocity system, on average, yielded higher comfort percentage for the whole-house with and without walls.
    - Air distribution system register locations do affect the comfort conditions in the house. Floor location of registers had the lowest comfort level

86. Thermal Performance of residential duct systems in basements (*Treidler, Burke. Modera, Mark P. ASHRAE Transactions. v 102 n 1 1996. p 847-858.*)

- This paper examined the typical effects of duct system operation on the infiltration rates and energy use of single-family residence with heating, ventilation, and air-conditioning (HVAC) systems in their basements.
- Results from a four-house field study and computer simulations are used to examine the potential for improvement in efficiency of air distribution systems
- From field measurement
  - o The unsealed rectangular sheet-metal duct systems typically found in basements leak significantly more than the flex-duct or round sheet-metal systems typically found in attics and crawlspaces.
  - o The pressure differentials seen by leaks in basement duct systems may not be same as those seen by leaks in typical attic or crawlspace duct systems, and it is caused by having much lower supply-side pressure in the basement systems
  - o Their large leakage area and significant conduction losses generally happened through uninsulated duct walls.
- From computer simulations
  - o The leakiness and lack of insulation on the typical ducts in a basement house can have serious energy-use consequences, with most of the savings being available on the heating side.
  - o Larger savings could be available in situations where the basement ceiling is insulated.
  - o Equipment sizing has a significant impact on the effectiveness of basement duct-system improvements, particularly on the air-conditioning side, and proper equipment sizing can save thermal losses up to 60%.

87. The remote control system for the next generation air conditioners (*Park, I G. IEEE Transactions on Consumer Electronics. v 47, n 1 Feb 2001. p 168-178.*)
    - This paper introduced a remote control system over the internet or telephone for the next generation air conditioner.
    - The next generation home cooling system consists of an Aircon-Server, and an Aircon-Gateway per a house, and Outdoor-Air-Conditioner per a house, and several Indoor-Air-Conditioners per a house.

88. Ventilation: Design considerations (*Tipping, J.C.; Harris-Bass, J. N.; Nevrala, D. J. Build Serv Eng v 42 Sep 1974 p 132-141.*)
    - A supply of fresh air for 2-3 persons in a typical living room (~ 20l/s) is more than adequate for safe operation of open-flue gas appliances having a heat input up to 20 KW (68,000 Btu/h).
    - The presence of a flue results in a higher more stable ventilation rate, less dependent on the open area.
    - The fresh air supply required in the dwelling can be more effectively controlled by mechanical ventilation than by natural means.
    - The open areas available for ventilation where an open-flue central heating appliance is installed will be adequate in a number of situations where an extract fan is fitted in the same room.

89. Ventilation systems for new and existing houses with electric baseboard heating (*Anonymous. Journal of Thermal Insulation & Building Envelopes. v 20 Apr 1997. p 297-300*)

- Investigates the effectiveness of five conceptual ventilation systems
    - An exhaust-only system comprised of local exhaust fans in the bathroom and kitchen areas.
    - An exhaust-only system comprised of local exhaust fans in the bathroom and kitchen areas supplemented with fresh air intake vents in all habitable rooms.
    - A partially distributed exhaust-only system that draws air from the second floor bedroom area and operates in conjunction with local exhaust fans in the kitchen and first story bathroom areas.
    - A partially distributed exhaust-only system that draws air from the second floor bedroom areas and operates in conjunction with local exhaust fans in the kitchen and first story bathroom areas, supplemented by a central fresh air intake vent
    - A fully ducted supply air system operating in conjunction with local exhaust fans in the kitchen and bathroom areas
- Ventilation systems for houses without forced air systems must utilize some form of distribution system

ELECTRICAL

90. A professional approach to home lighting (*Phillips, D.R.H. Light Light Environ Des v 70 n 2 Mar-Apr 1977 p 57-72*)
    - Use a number of smaller light sources in preference to a single lamp of higher wattage.
    - Light sources should be placed more than 45º from normal lines of sight, and if this is not possible the source itself should be shielded.
    - Points of potential danger such as staircases, isolated changes of level, basements, boiler rooms or loft spaces should be well lit either by daylight or artificial light.
    - Provide dimming control of certain fittings:
        - Permit variation of lighting intensity
        - Save electricity
        - Increase the life of the lamp
    - An alternative 'night circuit' employing low wattage sources will be more efficient.
    - Fluorescent lamp is of high efficiency and long life.
    - Choke noise remains a problem with the slimmer luminaries.

91. Efficient lighting strategies: wise design choices can meet lighting needs and save energy (*Building Technologies Program, Office of Energy Efficiency and Renewable Energy (EERE) (Brochure).6 pp. 2002 Bulletins Report No. BR-840-26467; DOE/GO-102002-0787.*)
    - Artificial lighting allows us to work and play inside and our homes independent of the time of day and is generally employed for three types of uses;
        - Ambient lighting – Provides general illumination indoors for daily activities and outdoors for safety and security.
        - Task lighting – Facilities particular tasks that require more light than is needed for general illumination, such as under-counter lights in kitchens, table lamps, or bathroom mirror lights.

- Accent lighting – Draws attention to special features or enhances the aesthetic qualities of an indoor or outdoor environment.
- Artificial lighting consumes almost 15 percent of household electricity, but use of new lighting technologies can reduce lighting energy use in homes by 50 to 75 percent.
- Energy-efficient lighting design focuses on methods and materials that improve both quality and efficiency of lighting;
    - Keep in mind that more light is not necessarily better. Human visual performance depends on light quality as well as quantity
    - Match the amount and quality of light to the performed function
    - Install task lights where needed and reduce ambient light elsewhere
    - Use energy-efficient lighting components, controls, and systems.
    - Maximize the use of daylighting.
- Interior lighting options
    - Daylighting – The use of windows and skylights to bring daylight into the home.
    - Indoor lighting technologies – Improve incandescent and fluorescent lighting
    - Indoor lighting Controls – Dimmer controls, photosensors, occupancy sensors, timers
- Exterior lighting options
    - Outdoor lighting technologies – High-intensity discharge (HID) and low-pressure sodium
    - Outdoor lighting controls – Photosensors, Motion sensors.
- In addition, this paper describes initial design recommendations, lighting principles and terms.

92. Environmental conditions of residential electrical connections (*Aronstein, J. Electrical Contacts, Proceedings of the Annual Holm Conference on Electrical Contacts 1998. IEEE, Piscataway, NJ, USA, p 230-238.*)
    - Electrical power in a home is distributed through a permanent built-in system of wiring and connections that are concealed in the structure.
    - The life of the connections is presumed to be equal to the life of the wire, capable of safe operation without maintenance for an indefinite time (the life of the structure)
    - Failures do occur involving deterioration at the contact interfaces to an extent that connections overheat under normal current loading, and the failures are often severe enough to result in hazardous consequences.
    - The working environment is an important factor that must be considered in residential wiring connection design and testing

PLUMBING

93. A discussion of water-conserving plumbing fixtures (*Fagan, Daniel. Hpac Heating, Piping, Air Conditioning. V 70 n 4 Apr 1998. p 43-47.*)
    - This paper mainly discusses the current state of water conserving fixtures and a review of issues to be resolved

94. **Health and Environmental Assessment of Plumbing systems** (*Brown, S L. Hazard Assess Chem Curr Dev. v 4. Publ by Academic Press, Orlando, FL, USA, 1985 p 243-300.*)
   - This paper discusses the implications for human health and the environment of increasing use of plastic plumbing systems in comparison with those of the materials (copper, iron, steel, lead, etc) they are replacing.
   - If any health or environmental effects do prove significant, they will probably be among the following possibilities: (1) cancer form the ingestion of water containing chlorinated hydrocarbon leachates from PVC or CPVC water pipe; (2) central nervous system damage from the ingestion of water containing lead from soldered copper water pipe; (3) intoxication or chronic toxicity from the inhalation of or dermal exposure to solvents by plumbers installing PVC, CPVC, or ABS pipes; or (4) central nervous system damage from the inhalation of lead fumes by plumbers installing copper pipe.

95. **Performance comparison of residential hot water systems** (*Wiehagen, J.;Sikora, J. L. 61 pp. 2003. Work performed by NAHB Research Center, Upper Marlboro, Maryland. Technical Reports*)
   - Using the Transient Energy Simulation Tool (TRNSYS), a simulation model was developed to estimate energy consumption for each hat water system
   - Annual simulations showed an increase in overall system efficiency of 12% for the demand water heater with a parallel piping distribution system over the storage tank water heater with copper piping for the high-use home and an increased efficiency of 26% for the low-use home
   - When normalizing the total output energy for each system, the electrical energy savings of the demand water heaters with a parallel piping system over the standard tank with a tree-piping system (tank/tree system) was 34% for the low-use home and 14% for the high-use home
   - Demand water heaters with a parallel piping distribution system are the most pronounced among the low-use homes because of higher standby and distribution losses with tank systems
   - The demand-parallel system was also less expensive to install and operate than conventional system
   - An alternative system design that uses a tree distribution system for cold water only, with demand heaters placed at each outlet, shows energy savings of nearly 30% for the high-use home and nearly 50% for the low-use home based on lower estimated delivery temperatures

COMMUNICATION

96. **A power line data communication interface using spread spectrum technology in home automation**: (*Shwehdi, M H. Khan, A Z. IEEE Transactions on Power Delivery. v 11 n 3 Jul 1996. p 1232-1237.*)
   - Methods of communication over a powerline, namely the X-10 and CE bus, help control electronic equipments at home.

- These pieces of equipment, if controlled, lead to efficient energy management and savings on the monthly electricity bill.
- The spread spectrum technology increases speed to 100-150 times faster than the X-10 system.

97. Voice controlled smart house: (*Yerrapragada, Chaya. Fisher, Paul S. Digest of Technical Papers - IEEE International Conference on Consumer Electronics. Publ by IEEE, IEEE Service Center, Piscataway, NJ, USA. 1993. p 154-155.*)
    - Defines the different areas in a house where automation is generally desired and the functions or capabilities associated with each of these areas.
        - Energy management
        - Communication
        - Security
        - Convenience
        - Entertainment
    - Defines a preliminary set of voice commands which would indicate the kind of vocabulary needed.
    - Finite Inductive Sequences (FIS), a pattern processing technique to develop the interaction scheme.

98. Whole house control utilizing a true computer network (Pikcklingis, Eric, 1994)
    - Describes a whole house controller based on a real-time distributed microprocessor network, and a distributed network of microprocessors allows remote interfaces to perform data collection and communication with a central controller.
    - The system hardware consists of a controller box and a Graphical User Interface (GUI) panel, and each controller box is capable of controlling up to six different zones

99. Wireless house calls: Using communications technology for health care and monitoring (*Boric-Lubecke, Olga. Lubecke, Victor M. IEEE Microwave Magazine. v 3 n 3 September 2002. p 43-48.*)
    - This article describes the application of communications technology for health care and monitoring needs, including home health-care technologies, telemetric sensors, and the remote sensing of vital signs through Doppler techniques using wireless components and terminals.

ENVIRONMENT

Moisture

100. A field test for correlation of air leakage and high moisture content sites in tightly built walls: (*Tsongas, G A. Nelson, G D. ASHRAE Transactions. Publ by ASHRAE, Atlanta, GA, USA. v 97 part 1, 1991. p 1-8.*)

- Evidence suggested that the source of the winter moisture buildup in the roof sheathing was moist indoor air migrating out through penetrations in the polyethylene air/vapor barrier.
- Many of the leaks resulted from improper sealing or poor workmanship.
- Uses design features other than extreme airtightness to take care of the problem, such as installing exterior insulating sheathing or constructing walls that are more vapor permeable on the outside so moisture will not build up inside the wall cavity.

101. Controlling moisture in the home: (*Brundrett, G. W. Building Energy Manage, Conv and Sol Approaches: Proc of the Int Congr, Povoa de Varzim, Port, May 12-16 1980 Publ by Pergamon Press, Oxford, Engl and New York, NY, USA, 1981 p 747-754*)

- Moisture control can be achieved by either mechanical ventilation or heat pump dehumidification.
- The space heating energy for a house depends upon three factors:
    - The thermal transmittance of the fabric
    - The operating temperature pattern of the dwelling
    - The ventilation rate
- Over-ventilation wastes energy.
- Under-ventilation leads to odors and moisture problems inside the house.
- Moisture affects comfort in several ways. The key parameters:
    - Water vapor pressure/absolute humidity
    - Relative humidity
- Lower relative humidities are more acceptable at higher air temperature.
- Below certain relative humidities, usually 70%, the spores will not germinate.
- Timber is particularly sensitive to deterioration in the damp and it is essential that structural timber does not exceed 20% moisture by weight. This is equivalent to an ambient relative humidity of 85%.
- An appropriate vapor barrier is positioned on the warm side of the insulation.
- Minimize moisture release in the home. Three major daily moisture sources:
    - Cooking
    - The people themselves
    - Washing and bathing
- Positive supply and extract ventilation systems for the whole house are now being manufactured in quantity and with the added provision of heat exchange (approx. 65% effective) between the inlet and the extract supplies. This solution is an attractive low energy one, but the air supply is manually controlled.
- In temperate climates a provision for a variable speed controlled by indoor relative humidity would be a desired option.

102. Crawl space moisture conditions in new and existing Northwest homes: (*Tsongas, G.A. ASHRAE Transactions. 1994, v.100, part 1, paper number NO-94-19-4, 1325-1332.*)

- Crawlspaces are most prevalent in the Pacific Northwest and the Southeastern United States (mild heating climates where freezing does occur but the frost depth is not very great). The most common configuration is a vented crawl space with underfloor insulation.
- Newer houses usually use plywood subflooring that is more airtight.

- In many Southeastern crawl spaces, serious moisture problems, such as extensive mold and mildew and wood decay, are rather prevalent.
- Pacific Northwest and other West Coast crawl spaces almost always perform satisfactorily from a moisture point of view.
- Code requirements for crawlspace ventilation and ground covers should not be the same as they are now in different geographic locations of the United States and Canada.

103. Investigation of crawl apace performance in British Colombia (*Fugler, D W. Moffatt, S D. ASHRAE Transactions. v 100 n 1 1994. ASHRAE, Atlanta, GA, USA. p 1411-1419.*)

- Mechanical ventilation in houses without forced-air heating: because better moisture barriers and improved drainage will not be 100% effective, there is still a requirement for removing moisture from heated crawl spaces.
- The code-required approach to crawlspace ventilation in Canada has been to rely on passive vents to remove excess moisture on a seasonal basis.
- The 1991 research showed that vents are of variable effectiveness due to:
    - Construction practice
    - Moisture loads
    - Interpretations of venting requirements by builders and householders
- Recommendations:
    - Improve drainage and moisture barrier requirements
    - Clarify the distinction between heated and unheated crawlspaces
    - Treat heated crawlspaces as if they were shallow basements, with provision for heating and fresh air supply.
- Some municipalities now rely on more stringent moisture source control, with less emphasis on crawlspace ventilation.

104. Moisture management strategy in wood-frame stucco wall – observation from hygrothermal simulation: (*Mukhopadhyaya, P. Djebbar, R. Kumaran, K. Reenen, D V. World Congress on Housing, Housing Process & Product, June 23-27, 2003, Montreal, Canada*)

- Optimum vapor diffusion strategy in a wood-frame stucco wall can be determined if well defined input parameters such as construction details, material properties and boundary conditions are available.
- If the overhangs can deflect or prevent the liquid water entry into the stucco cladding then it is very effective in reducing the overall moisture load in the protected area.
- Partial overhangs do not prevent liquid moisture entry over the entire height of the exterior face of stucco cladding and would not be able to enhance the long-term moisture performance of the wall assembly.
- Only the overhang capable of protecting the entire exterior face of the wall assembly would be effective to enhance the overall moisture performance of the wall.

105. Moisture control for buildings (*Lstiburek, J. ASHRAE Journal. Vol. 44(2) February 2002. p. 36-41*)

- Hygro-thermal regions, rain exposure zones and interior climate classes are environmental loads used in applying moisture engineering to building envelopes and mechanical systems.

- If moisture accumulates beyond about 16% by weight, wood surfaces are likely to develop mold.
- Steel studs have no water storage capacity. Gypsum sheathing can store approximately 1% moisture content by weight before mold colonization occurs.
- Constructing the average home with steel studs and gypsum sheathing yields a hygric buffer capacity of 5 gallons (19 L), if with masonry exterior walls and masonry cladding, the buffer is 500 gallons.
- More thermal insulation increases the swell time of moisture in the assembly.
- Cold climate:
    - Conditioned space should be maintained at relatively low moisture levels through the use of controlled ventilation (dilution) and source control.
    - Install air barriers and vapor barriers on the interior of building assemblies.
    - Let the building assemblies dry to the exterior by installing vapor permeable materials towards the exterior.
- Hot and humid climate:
    - Air barriers and vapor barriers are installed on the exterior of building assemblies.
    - Let the building assemblies dry to the interior by using permeable interior wall finishes and installing cavity insulations without vapor barriers. Avoid any impermeable interior wall coverings such as vinyl wallpaper.
    - Conditioned spaces are maintained at a slight positive air pressure with conditioned (dehumidified) air to limit the infiltration of humid outdoor air.
- Mixed climates:
    - Adopt a "flow-through" approach by using permeable building materials on both the interior and exterior surfaces of building assemblies.
    - Require both air pressure control and interior moisture control.
    - Install the vapor barrier roughly in the thermal "middle" of the assembly.

106. Reduction of moisture in wood joists in crawl spaces – a study of seventeen houses in Southern New Jersey (*Stiles, L. Custer, M. ASHRAE Transactions. v 100 n 1 1994. ASHRAE, Atlanta, GA, USA. p 1314-1324.*)
    - A combination of adding a moisture barrier (polyethylene) to the bare soil and foundation walls, closing foundation vents, and sealing air leaks at the rim joist reduced moisture content of exposed floor joists by 3-5%, while just applying the moisture barrier reduces moisture content by about one-half that amount.
    - The air distribution system appears to play a role in reducing moisture levels in the crawl space.

107. The control of wind cooling of wood frame building enclosure (*Timusk, J. Seskus, L. Ary, N. Journal of Thermal Insulation. v 15 July 1991. p. 8-19.*)
    - Moisture problems could be largely avoided by providing airtight sheathing at building corners by moving the air barrier, customarily located on the room-side of the wall insulation, to the weather side where it would perform two functions.
    - Such an air-permeable air barrier, or rather an air diffusion control membrane, could be utilized to provide fresh air into the individual rooms of a house, and that walls could be built which act as heat-recovery ventilators with a solar collection potential.

Air Quality

108. **Air humidity requirements for human comfort** (*Toftum, J. Fanger, P. O. ASHRAE Transactions. v 105, Part 1, 1999, 641-647.*)

- An upper humidity limit based on a relative skin humidity of 0.54 corresponding to 20% dissatisfied resulted in a maximum permissible humidity level near 100% RH.
- For respiratory discomfort, much more stringent requirements for indoor air humidity were defined. (ASHRAE Addendum 55a).
- The limits based on skin humidity were less restrictive.

109. **Passive ventilation for residential air quality control** (*Axley, J. ASHRAE Transactions. v 105 (PART 2) 1999. 864-876*)

- ASHRAE: 0.35 air changes per hour but not less than 15 cfm (7.5 l/s) per person for living areas.
- Humidity in habitable spaces preferably should be maintained between 30% and 60% relative humidity to minimize growth of allergenic or pathogenic organisms.
- Passive ventilation systems offer the attractive possibility of providing background ventilation for air quality control in houses using the free, natural forces of wind and buoyancy effects.
- The traditional Passive Stack Ventilation (PSV) system may be expected to under-ventilate during mild conditions, over-ventilate during cold and/or windy conditions, and suffer from occasional backdrafting and cold drafts.
- Innovative self-regulating inlet and outlet vent devices appear to provide the means to solve these problems.
- A general design method to size system components for the environmental conditions unique to each American climate in needed.

110. **Pressure differences affecting radon entry in new residential construction** (*Nuess, Mike. Environ Eng Proc 1989 Spec Conf. Publ by ASCE, New York, NY, USA. p 304-311.*)

- Reduce the radon entry level:
  - Substructure sealing to reduce openings between the soil and the building
  - Superstructure sealing to reduce to overall volume flow rate of air exchange
  - Providing outdoor air supply to the house at a low level, thereby reducing the effective chimney height of the house
  - Actively establishing an overriding pressure field between the house and the surrounding soil
- A majority of the total openings in the building envelope oriented downwind will increase soil gas infiltration.
- The impact of wind on radon infiltration can be reduced by constructing as tight a construction as possible.
- Furnace combustion air increases radon entry.
- The provision of outdoor combustion air reduces the negative pressure, the danger of backdrafting and spillage of combustion gases into the house.
- Sealing ductwork can significantly reduce the path of radon entry.
- The design of balanced distribution systems, and provisions for regular maintenance and balancing, can minimize the system's contribution to negative pressure.

- Intermittent operation of bath and kitchen fans and dryers can contribute to an increased pressure difference between soil and house.
- Basement pressurization is sometimes not recommended.
- An additional useful measure is the addition of a soil gas barrier on the surface of the soil.
- A fan could be added to increase the rate of crawlspace ventilation.
- A frequently used approach in Sweden is one wherein a sealed crawlspace is mechanically ventilated by exhaust air from the conditioned living space.
- The soil/house pressure difference can be broken or greatly reduced by merely opening several windows in the lower portions of the building.
- Actively ventilating the soil immediately beneath and adjacent to the building.

111. Residential Pollutants and ventilation strategies: moisture and combustion products: (*Hadlich, D. E. Grimsrud D. T. ASHRAE Transactions. v 105 (PART 2) 1999. p 833-848*)

- Home dampness and the individual mold and water variables in U.S. and Canadian homes were all significantly associated with increased respiratory symptoms, and similar results were reported for bronchitic and asthmatic symptoms.
- Moisture and humidity control has been shown to be effective in reducing house dust mites and fungal allergen density and exposure.
- Any large moisture source must first be controlled at the source.
- A proper ventilation system should provide constant minimum ventilation values.
- Indoor-outdoor pressures must be balanced. The ventilation system should not draw in moisture, soil gases or backdraft combustion appliances.
- The system should not force moisture into wall systems.
- The minimum ventilation rate must be delivered to each room effectively.
- The attached garage is part of the indoor air zone in many houses. Care in design and construction must be used to assure that the air zones are not coupled.
- Different control strategies for treating the pollutant emissions from gas and other combustion appliances:
    - Task ventilation should be used to remove cooking products and combustion pollutants from cooktops and exhaust it outdoors.
    - Excess depressurization should be avoided in houses containing atmospherically vented combustion equipment.
    - If strong combustion sources are present in the house they should be isolated from the occupied zone and supplied with their own air supply and exhausted so that cross contamination with the remainder of the house air does not occur.
    - When outdoor combustion sources are the dominant combustion pollutant sources, consider limiting the outdoor ventilation air temporarily. If the conditions persist or reoccur frequently, a filtration system should be considered.

112. Residential pollutants and ventilation strategies: volatile organic compounds and radon (*Grimsrud, David T. Hadlich, Daniel E. ASHRAE Transactions. v 105 (PART 2) 1999. p 849-863*)

- ASHRAE Standard 62.2 “Ventilation and Acceptable Indoor Air Quality in Low-rise Residential Buildings.”
- EPA’s value of 150 Bq/m^3 (4 pCi/L) as a radon concentration limit.

- Volatile organic compounds: continuous evaluation of irritation in eyes, nose, and throat showed significant correlation to exposure both at mixture concentrations of 5 and 25 mg/m^3.
- Particles, in particular floor dust, can act as carriers of VOCs and semi-volatile organic compounds (SVOCs).
- Building design features are strategies that isolate the living space from strong nearby sources of VOCs (such as garages).
- Pressurizing the building cannot be used in cold climates. It would reduce entry of soil gas but simultaneously force warm, humid indoor air into the cold parts of the walls and cause structural failure.
- Active Soil Depressurization (ASD) commonly reduces indoor radon levels 90-95%.
- Pressurization of a basement in an effective mechanism to prevent radon entry into the structure.

113. Resolving the radon problem in Clinton, New Jersey, houses (*Osborne, Michael C. Environment International. v 15 n 1-6 1989. p 281-287.*)
- The potential entry of soil gases from around the outside of the ducts and into the house via the heating registers.
- For the slab-on-grade portion of the split-level houses
    - Seal the slab just below the registers with concrete and route new heating ducts into the attic.
    - A plastic pipe with an in-line fan was then connected to the abandoned heating ducts, creating suction in the ducts and surrounding sub-slab area.
    - Seal floor/wall perimeter cracks.

114. The development of a method of determining air change rates in detached dwellings for assessing indoor air quality (*Yuill, G.K. 1991, ASHRAE Transactions, v 97 (part 2) paper number IN-91-12-2, 896-903.*)
- ASHRAE standard project committee 136P is presently developing a standard entitled "A Method of Determining Air Change Rates in Detached Dwellings for Indoor Air Quality Purposes."
- A procedure for calculating the annual average air change rate of a house based on a measurement of the airtightness of the house and a single parameter that express the effect of the local weather on infiltration.

Miscellaneous:

115. Integrated comfort sensing system on indoor climate (*Kang, Jeongho. Park, Sekwang. Sensors & Actuators A-Physical. v 82 n 1 2000. p 302-307.*)
- An integrated comfort sensing system on indoor climate can provide an effective means of measuring the comfort sensing of a human being.
- Temperature/humidity and air flow sensors
- ASIC of diving and amplifying circuit using CMOS technology
- The sensing system is a practical means of monitoring predicted mean vote (PMV) and comfort sensing vote (CSV) indices and feedback-controlling in automobiles, homes, and hospitals, etc.

116. Residential water conservation (*Karpiscak, Martin M. Foster, Kennith E. Schmidt, Nancy. Water Resources Bulletin. v 26 n 6 Dec 1990 p 939-948.*)

- Water-conserving fixtures
- Rainwater harvesting
- Graywater reuse system
- Water savings help
  - Alleviate the demand for a diminishing resource
  - Reduce both water and energy bills for households
  - Decrease in fossil fuel use
  - A decrease in air pollutants such as carbon dioxide

117. Thermal comfort for sedentary and moderate activity levels (*Chamra, Louay M. Huynh, Kien. Hodge, B K. ASHRAE Transactions. v 108 PART 1 2002. p 428-434.*)

- Human thermal comfort is dependent upon dry-bulb temperature, mean radiant temperature, relative humidity, air velocity, clothing insulation, and activity level.
- On the thermal sensation, the temperature, not the relative humidity, is the dominant factor.
- The combination of all six variables listed above affect thermal comfort. However, the dominant factor is the activity level. The subjects who engaged in the higher-met activity felt significantly warmer than those who were sedentary.
- The gender variable had essentially no effect on the comfort level.
- ANSI/ASHRAE standard 55-1992 fails to predict thermal comfort at the 2.3 met activity level.

WHOLE HOUSE

118. A comprehensive approach to the assessment of a housing problem with the emphasis on a search for improvements (Klecka, Brett. *Int J Hous Sci Appl* v6 n 1 1982 p 77-94.)

- A new system approach to comprehensively assess a housing problem and search for improvements:
- The housing matrix:
  - Identify the factors of the infrastructure of conditions.
  - Prepare a housing matrix
  - Use the housing matrix and prepare a specific matrix appropriate to the selected factor for the assessment.

119. A house built of whiskers (*Geiger, Greg. American Ceramic Society Bulletin. v 79 n 3 2000. p 47-48.*)

- Houses are pre-fabricated in segments at a factory using steel framing and an exterior shell made of ceramic whisker reinforced resin (designed to look like a natural stone foundation and wood siding).
- The life of house is 150 years and the panels are 100% recyclable.

120. Building design principles for hot humid regions (*Givoni, B. Renewable Energy. v 5 n 5-8 Aug 1994. p 908-916*)

- Building layout
- Orientation of the main rooms
- Size and details of openings
- Rain protection and ventilation
- Thermal mass issues
- Hurricane protection
- Verandas
- Relationship of the building to the ground

121. Building America program overview (DOE, 2001)

The whole-house approach

- Advanced framing systems: using 2x6 studs on 24" spacing instead of the more common 2x4 studs on 16" spacing: improving the insulating value of the walls and reducing labor and lumber required to assemble the framing.
- SIPs and other innovative wall systems may be used to create an airtight, highly insulating wall construction.
- Integrated envelope sealing package
- Energy-efficient windows: allow the use of shorter ducts that are easier to seal and less expensive to install
- Optimally sized mechanical systems
- Ductwork improvements
- Factory construction

122. Canadian experience in healthy housing (*Shaw, C Y. Magee, R J. Swinton, M C. Riley, M. Rober, J. International Symposium on Current Status of Indoor Air Pollution by Organic Compounds and Countermeasures for Healthy Housing, Tokyo, Japan, 2001, pp. 31-35*)

- R-2000 (1982): a 50% reduction in the energy consumption for space and hot water heating compared to houses built to the 1975 National Building Code of Canada.
- Advanced Houses Program (1991): used the same performance-based standard as for R-2000 houses, but went beyond energy efficiency into issues such as selection of environmentally-friendly building materials, indoor air quality, water and waste reduction, recycling, and elimination of CFCs.
- Feature to meet R-2000 specification:
    - Low emission carpet, its total area less than 50% of the total floor area including the basement.
    - Medium efficiency pleated air filter with minimum 10% ASHRAE average dust spot test.
    - Water-based paints and varnishes, and flooring adhesives.
    - Pre-finished wood flooring.
    - Linoleum or vinyl floor tiles.
    - Kitchen and bathroom cabinets with solid wood doors sealed with approved low-emission sealer.

    - Floor sheathing and underlayment sealed on all exposed surfaces with approved sealer. Floor sheathing used only phenol-based resins.
    - The overall airtightness value was measured to be less than 1.5 ac/h at 50 Pa.
    - Central air distribution system with a heat recovery ventilator (HRV) and an electronic air cleaner.
    - Air change rate for low energy houses is greater than that for conventional houses.

123. Cold hands, warm health? : climate, net takeback, and household comfort (*Schwarz, Peter M. Taylor, Thomas N. Energy Journal. v 16 n 1 1995. p 41-54.*)

- Insulation reduces marginal heating cost and may lead to a takeback effect of higher wintertime thermostat settings, with a consequent dilution of energy savings.
- Additional insulation could permit a lower thermostat setting by reducing drafts and radiation while increasing moisture retention, thereby enhancing comfort.
- Net thermostat takeback is on the order of 0.05ºF, leading to an energy takeback that ranges from 1-3% of potential energy savings, depending on climate and house size. Dilution of energy savings due to takeback increases with house size.

124. Construction systems overview (design for lifestyle & the future)

- Choosing an appropriate construction system for climate and location will increase thermal comfort, lower construction and maintenance costs and reduce the overall environmental impact.
- This document analyzes the merits of some common construction systems and explains the process of choosing or developing the best combination for your needs in your climate and geographic location.

125. Development of Medallion 2000 award advanced house specification (Siviour, J. B., 1991)

- Medallion award specifications cover a number of features in addition to the 1990 Building Regulations.
- The additions are: double glazing in place of single glazing; a high degree of structural airtightness; and whole house mechanical ventilation with heat recovery.
- The objective of Medallion 2000 is simple to build and operate and applicable to the general housing market, and the requirement to be all-electric.

126. Integrating affordability, energy and environmental efficiency, air quality and disaster resistance into residential design and construction (*Cook, Gary D. Proceedings of the Intersociety Energy Conversion Engineering Conference. v 2 1995.. p 447-452.*)

- The purpose of this paper is to review the characteristics of features of good home design and construction and explore the integration of them into the ideal residential structure.
- A compact two story structure:
    - The first floor is constructed using insulated, strong, and high thermal mass masonry system resistant to flood, wind, fire, and termite damage.

    - The second floor constructed using a lighter reinforced wood frame with between stud insulation coupled with exterior insulated sheathing to minimize thermal bridging across studs.
    - Optimizing floor plan such as separating living and sleeping areas present opportunities for efficient split HVAC zoning, natural ventilation, and solar passive adaptation.
    - The design emphasizes the 4, 8, and 12 foot dimensioning for waste reduction; selection of environmentally friendly building materials, such cellulose insulation; and efficient lighting and appliances.
    - Providing improved indoor air quality such as prudent duct selection, design and location, use of radon barriers, omission of carpeting, and control of moisture.
- Indoor air quality:
    - Elimination of pollution.
    - Tight building construction practices
    - In hot humid climates, never use vapor retarders including vinyl wall coverings on the inside of exterior walls
    - A plastic vapor seal under floors and concrete slabs should be installed with holes or tears sealed to prevent moisture and toxic soil gas entry
    - Cellulose insulation is preferred over fiberglass
    - Drying of construction materials and the structure prior to sealing and painting
    - Use gutter and down spouts to carry rainwater away from the building.
    - Central vacuum system with an outside exhaust preferred.
    - Maintain a positive air pressure within a building.
    - Ventilation should be conditioned and filtrated such that the indoor air is maintained at a temperature between 70 to 78ºF and 30-60%.
    - The HVAC system should be sized for the expected sensible and latent load.
    - Combustion appliances should be properly vented and have a dedicated combustion air supply.
    - Return air and ventilation air intakes should be placed well away from moisture and potential pollution sources such as garage dumpsters and cooling towers.
    - Galvanized steel ducts insulated and wrapped with a vapor retarder on the outside are preferred to fiber glass.
    - Bedrooms should have return air ducts or doors with proper undercutting or louvers
    - Ducts located in the conditioned space
    - Avoid carpets; hardwood and ceramic floors are preferred.
    - Avoid particle board containing formaldehyde.
    - Select furnishings that have low moisture adsorption capability, such as wicker, cane and glass.
    - Use insect baits instead of toxic insecticides
    - Shrubbery should be no closer than 2’ from the building.
    - Select low maintenance landscaping and drip irrigation.

127. **Integrated systems performance and air quality and moisture management in a hot humid climate** (*Holton, John K. Proceedings of the Air & Waste Management Association's Annual Meeting & Exhibition 1997. Air & Waste Management Assoc, Pittsburgh, PA, USA.. 10p 97-WP95.02.*)

- The latent load control (LLC) cycle heat pump appears capable of providing satisfactory humidity management for a positively ventilated house in a hot humid climate.
- Changing the LLC to a cycling operation results in an approximately 16% reduction in dehumidification energy.
- Moisture removal is excellent with full fresh air flow, including RA leakage flow, as long as the air handling unit (AHU) fan cycles with the compressor.
- A need to develop a ducted fresh air inlet system that employs the AHU draw for fresh air introduction rather than a separate fresh air fan.
- Return air pathway from each room should be pressure tested for adequacy. Additional door undercut or transfer ducts/grills may be necessary for proper pressure management.
- New houses need positive ventilation. This is particularly critical in houses with gas cooking appliances.
- The fresh air ventilation system with fresh air fan provides acceptable indoor air quality.

128. **Modular HVAC simulation and the future integration of alternative cooling systems in a new building energy simulation program** (*Strand, R K. Fisher, D E. Liesen, R J. Pedersen, C O. ASHRAE 2002*)

- This paper describes the portions of a new energy simulation program (EnergyPlus) related to modeling HVAC systems and outlook for using this program to model alternative cooling systems.
- Potential future models:
    - The radiant system linked to a cooling tower or some other condenser type, such as a ground loop, a ventilated slab
    - A hybrid system that combines an air loop and a radiant system.

129. **Residential ventilation and energy characteristics** (*Sherman, Max H. Matson, Nance. ASHRAE Transactions. v 103 n 1 1997. ASHRAE, Atlanta, GA, USA. p 717-730.*)

- The purpose of this report is to ascertain the energy liability associated with providing the current levels of ventilation and to estimate the energy savings or penalties associated with tightening or loosening the building envelope while still providing ventilation for adequate indoor air quality.
- ASHRAE standards (e.g. 62, 119, and 136) are used to determine acceptable ventilation levels and energy requirements.

130. **Selecting whole-house ventilation strategies to meet proposed standard 62.2: energy cost considerations** (*Wray, C P. Matson, N E. Sherman, M H. ASHRAE Transactions. v 106 Part 2, 2000. p 681-691.*)

- Most new construction is tight enough that infiltration will not provide sufficient ventilation.

- The marginal energy costs to provide ventilation with a central exhaust-only system in a typical new house would be on the order of 50¢ per day. This can be compared to an infiltration-only cost of $2 per day to condition the air in a typical existing house.
- In most cases, the first choice of mechanical systems is a central exhaust-only system. It has low first cost, ease of installation, and minimal operating cost.
- In hot, humid climates or if the envelope is exceedingly tight, either a heat recovery ventilator system (HRV) or a supply system might be preferable to avoid depressurization problems.
- In cold climates with high heating costs, an HRV might be more cost-effective.

131. Simulating combined thermostat, air conditioner, and building performance in a house: (*Henderson, H I. ASHRAE Transactions. Publ by ASHRAE, Atlanta, GA, USA. v 98 pt 1 1992. p 370-380.*)

- Using this model, the following were investigated:
    - The relative importance of various thermostat parameters (anticipator, switch dead band, and bimetallic element)
    - The effect of extra thermal mass representing furniture on AC system cycling rate
    - The effect of AC system time constants and oversizing on efficiency
    - The impact of a delay time for latent capacity on indoor humidity levels.
- For conventional thermostats with an anticipator and bimetallic sensing element, the dominant parameters that affect the cycling rate are anticipator temperature rise and switch dead band.
- When a conventional thermostat is used, adding furniture to the home decreases the cycling rate by 15%.
- When a thermostat without an anticipator is used (e.g., an electronic, programmable thermostat), adding furniture reduces the cycling rate by a factor of 4.
- Electronic programmable thermostats may negatively impact equipment reliability and energy use in houses that are lightly furnished.
- Assuming an AC system time constant of 60 sec., the efficiency loss due to cycling for this typical summer day in Miami is 9.1%.
- Oversizing the AC system in the modeled house by 50% (three tons instead of two tons) results in 8.9% loss of efficiency.
- A similar efficiency penalty would also be expected when the load on an existing home is decreased, for instance, by adding insulation.
- Some studies have noted that there is typically a longer delay for latent than for sensible capacity on AC system startup. This latent delay was found to have only a minimal impact on indoor humidity levels.

132. Smart enabling system for home automation (*Stauffer, H B. IEEE Transactions on Consumer Electrics. V 37 n 2 May 1991 p xxxvp.*)

- This paper describes an "enabling system" that provides the common resources needed for home automation in a multi-product, multi-vendor environment: controller, housewide bus, communications protocols, standard interfaces, and basic user controls.

133. Study of natural ventilation of houses by a metallic solar wall under tropical climate: (*Hirunlabh, J K. Kongduang, W. Namprakai, P. Khedari, J. Renewable Energy. v 18 n 1 1999. p 109-119.*)

- The metallic solar wall (BSW) can reduce significantly heat gain in the house by developing air circulation to improve the thermal comfort.
- The described passive solar system could also be used with reverse function, i.e. to admit ambient air and to inject hot air into the house in cooler regions to provide heating during winter.

134. Sustainability attributes of the IBACOS house (*Holton, John K. Proceedings of the 1996 Air & Waste Management Association's 89th Annual Meeting & Exhibition. Nashville, TN, USA. 19960623-19960628. Conference Code: 46962.*)

- The basic objectives of the IBACOS technical development program:
  - Energy efficiency
  - Environment responsiveness
  - Top quality
  - Quick to construct
  - Affordable
  - Adaptable to a variety of lifestyles
- A high performance shell: better insulated, more airtight, low-e windows with a higher R value, better insulated and more watertight foundation using pre-cast concrete panels. Smaller central equipment is possible due to reduced design loads.
- Use of fluorescent lighting throughout the house saves energy.
- Use of recycled materials:
  - Materials made from crop sources
  - OSB and small dimension lumber
  - Cellulose insulation and thermoply sheathing based on recycled newspaper
  - Plastic shingles made from recycled computer cases
  - Polyolyfin carpet from soda bottles
  - Gypsum board using recycled paper for the skins
- Reduction in materials used: the concrete panel foundation system uses less concrete.
- Waste reduction: Plant panelized construction, erecting gypsum board walls and ceilings in the partition-free interior, application of cellulose insulation.
- Durability: the vented eve/ridge of the EQA house keeps a cold roof, and thus no ice dam formation.

135. The effect of increasing house insulation on electric heating equipment design (Siviour, 1980)

- Free heat has the potential to provide a large proportion of total heating requirement in a highly insulated house even on a mid-winter's day.
- Individual room control of the heater is needed if most of the free heat is to be captured.
- Rooms such as a diner/kitchen with a large and very variable free heat input need heaters with an output which rapidly responds to temperature control.
- Storage heating equipment is best sited in the hall where there is little free heat generated.

- Bedrooms could be largely heated from the hall storage heater during the daytime by warm air drift. The direct acting heater in the bedrooms can be timed to take most of their heat during the off-peak period.
- Overload capacities will need to be greater than the traditional 20% provided in uninsulated houses.

136. The effects of infiltration and insulation on the source strengths and indoor air pollution from combustion space heating appliances (*Traynor, G W. Apte, M G. Carruthers, A R. Dillworth, J F. Prill, R J. Grimsrud, D T. Turk, B H. Japca (Journal of the Air Pollution Control Association). v 38 n 8 Aug 1988 p 1011-1015.*)
    - Energy conservation strategies for residences involve reducing house air exchange rates, which may cause an increase in pollutant levels.
    - It is possible to maintain or even improve indoor air quality if the indoor pollutant source strength can be reduced.
    - Increasing the insulation level of a house is a means of achieving energy conservation goals and, in addition, can reduce the need for space heating and thereby reduce the pollutant source strengths of combustion space heaters.
    - This paper investigates the indoor air quality trade-off between reduced infiltration and increased insulation in residences for combustion space heaters.
    - Indoor air pollution levels in houses with indoor combustion space heating pollution sources can be held constant (or lowered) by reducing the thermal conductance by an amount proportional to (or greater than) the reduction of the air exchange rate.

137. Ultrasonic humidification: system integration, energy, and indoor air quality engineering issues (*Mumma, S A. Ke, Y P. Sevigny, S P. ASHRAE Trans. 1997, v 103 Part 2, p 894-905.*)
    - Ultrasonic humidification requires a different approach when sizing the heating coil, which must not only be able to temper the mixed air but must also be able to provide sufficient heat to overcome the evaporative cooling effect of the humidifier (i.e. humidification energy)
    - In steam humidification systems, the heating coil is not required to provide any of the humidification energy.
    - The ultrasonic humidifier is a more energy-efficient means of humidity control than steam humidification, but great care must be exercised to ensure that the tendency toward low ventilation air does not cause the systems to operate in violation of ASHRAE standard 62-1989.

138. Unvented-cathedralized attics: where we've been and where we're going (*Rudd, Armin F. Lstiburek, Joseph W. Ueno, Kohta. Proceedings Aceee Summer Study on Energy Efficiency in Buildings. v 1 2000. p 1247-1259.*)
    - The unvented attic houses yielded both cooling and heating energy consumption savings over the conventional 1:150 vented attic house.
    - The maximum measured plywood roof sheathing temperature increase of 21°F for the unvented attics was less than the temperature variation that would be expected by changing from tile to asphalt shingles of any available color.

- The maximum measured roof sheathing temperature of 154°F for the unvented attics was well within acceptable temperature limits.
- The advantages for the hot-humid climate are expected to be even greater than for the hot-dry climate.

139. Vented and sealed attics in hot climates (*Rudd, A F. Lstiburek, J W. ASHRAE Transactions. v 104 n 2 1998. ASHRAE, Atlanta, GA, USA. p 1199-1210.*)

- In the hot humid climate, the best solution to eliminate the potential for moisture condensation in attics may be to keep the moisture out of the attic altogether by sealing the attic to the outdoors.
- The building codes usually report the required ventilation area as a ratio of the net free vent area to the horizontal projection of attic floor area. Typically, if at least 50% of the ventilation area is in the upper portion of the space and a continuous ceiling vapor retarder in cold climates is installed on the warm side, the required ratio is 1:300; otherwise, it is 1:150.
- When compared to typically vented attics with the air distribution ducts present, sealed "cathedralized" attics (i.e., sealed attics with the air barrier and thermal barrier (insulation) at the sloped roof plane) can be constructed without an associated energy penalty in hot climates.

140. Whole house ventilation strategies: (*Manufactured housing research alliance Jan, 2003. http://www.research-alliance.org/pages/newslett.htm*)

- ASHRAE recommends minimum whole house ventilation equal to 0.35 air changes per hour for residences.
- Previous studies of manufactured homes indicate that approximately 0.25 air changes per hour are provided by natural infiltration.
- 39 papers were reviewed in this report.

141. Whole-house ventilation systems – improved control of air quality: (building technologies program)

- Balanced, heat-recovery ventilation systems
- Integration with forced-air heating and air conditioning systems