Arnold Schwarzenegger
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ATTACHMENT #1
LITERATURE REVIEW SUMMARY REPORT

PIER FINAL PROJECT REPORT

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Prepared By:
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Database Development of Mold Incidences in California Homes

Task 2
Situation Analysis

Final Report on Subtask 2.1
Literature Review Summary Report

July 2004

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Task 2 – Subtask 2.1 Final Report

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Executive Summary

Modern residential and commercial construction practices in California have increased the overall building energy efficiency, but have also resulted in conditions that may be conducive to water intrusion and rapid microbial growth. There is a great need to understand the susceptibility of various construction practices and building assemblies to the intrusion of water and growth of mold.

The ultimate objective of Subtask 2.1 is to provide a preliminary set of recommendations identifying moisture and mold resistant building assemblies and practices for further investigation and application in the Laboratory Evaluation, Demonstration Homes, and Information Product Dissemination tasks. To accomplish this objective, a literature review and interview process was implemented.

A total of 16 interviews and 85 literature reviews were completed. The construction processes in homes were found to be key contributors to the problem, i.e., it may not be the window that fails, but rather the inadequate or incorrect flashing installation that leads to water intrusion. A set of recommendations emerged from the interview and literature survey process to potentially solve some of these water problems through work in later project tasks. Those recommendations include, but are not limited to:

- Upgrade window (and door) installation techniques, standards and codes to foster proper flashing, etc.
- Improve plumbing systems and installation practices to ensure pressure testing before operation, eliminate punctures by other trades during construction, etc.
- Consider alternatives to, or enhanced means of water intrusion protection for, hygroscopic building materials such as OSB in wall and roof assemblies. Likewise consider alternatives to mold food sources, e.g., substitute fiberglass paper for cellulose on drywall.
- Evaluate proper placement of vapor barriers in wall assemblies, including “smart” vapor barriers, to inhibit water vapor transport but allow drying under saturated air conditions and new home humidity pulldown.
- Produce a builders’ manual to check during construction for known anomalies leading to water intrusion. Likewise, produce a manual for homeowners to properly maintain a residence to prevent moisture intrusion and mold growth.

Note this reported work is NOT an all inclusive survey, but rather this subtask is a targeted effort to serve later project efforts by providing this preliminary set of recommendations identifying moisture intrusion resistant building assemblies and practices for further investigation and application in the later Laboratory Evaluation, Demonstration Homes, and Information Product Dissemination task activities. Also note this document is NOT static. Over the course of this project as additional literature and new key contacts surface that are essential to the success of ongoing tasks, summaries of those reviews and interviews will be included in an updated version of this document. This is the first version of the document.

The Gas Technology Institute (GTI) is the prime contractor for this California Energy Commission Public Interest Energy Research (PIER) project with the University of Illinois at Chicago Energy Resources Center (UIC-ERC) as the key project subcontractor that performed Subtask 2.1.

Background

Overview

A critical factor leading to the dramatic increase in mold in buildings is the change in building envelope construction. In the past, building wall systems were more massive, poorly insulated, and drafty. This allowed any water intrusion into the wall system during wetter weather conditions (series of damper days) to be taken up by materials with significant moisture storage. The rate of wetting and the accumulation of water in the wall materials did not typically exceed the wall's moisture storage capacity and its ability to then dry, or its rate of drying, under drier weather conditions (series of drier days).

Modern building wall systems are lighter weight, better insulated, and tighter. Lighter weight materials provide less of a moisture buffer, so water can accumulate quickly upon wetting and saturate the materials before drying, creating very high relative humidity levels, even liquid water, in wall systems. The higher levels of insulation reduce drying potential further by limiting energy throughput in the wall system that can drive off collected moisture. Infiltration barriers further reduce drying potential by limiting the movement of air through the wall system that would otherwise carry away water vapor. And finally, today's buildings are typically air conditioned creating a lower moisture level indoors than outdoors and a greater driving force for moisture to migrate inward.

Hence, building envelopes constructed today do not "breathe" like their counterparts of the past. When water intrudes into envelope cavities in a sustained manner or does not dry quickly, mold may propagate due to "trapped" moisture. Also, present day construction increasingly involves the use of wood with high moisture content for framing. This "green" lumber is preferred by both carpenters for ease of framing construction versus kiln dried lumber which is often warped; and by builders for reduced costs up-front and fewer callbacks later with warped lumber "nail pops", etc.. Once the wall cavity is sealed, the retained moisture contributes to favorable conditions for mold growth. Damp insulation and resulting mold growth compromise building envelope energy efficiency, damage building materials, and affect the health and productivity of occupants. Once mold growth occurs, it is costly to remove and often results in expensive insurance claims and even litigation. By understanding the demographics of mold incidences and building construction parameters affecting mold growth, it may be possible to mitigate or eliminate mold growth, thereby limiting heating and cooling energy losses, reducing building remediation costs, and avoiding human exposures to unhealthy indoor environments.

Since little work has been done to date examining the susceptibility of common building practices to mold growth in the different California climate zones, there is a great need for further investigation. For instance, a wall assembly consisting of cellulose insulation with high moisture content wood framing and paper-backed drywall with vinyl wallpaper is known to be highly susceptible to rapid mold growth under high moisture conditions. On the other hand, foamed insulation with proper water drainage channels to outdoors and properly dried wood framing along with fiberglass-backed drywall coated with paint containing mildicide is likely to be less susceptible to mold growth in the presence of moisture. In the mold-susceptible assembly, a larger area of mold coverage could

make it necessary to replace the entire wall assembly, whereas the mold-resistant assembly with a smaller area of mold coverage could be cleanable based on existing mold remediation guidelines given the same water intrusion scenario.

This project will enhance the understanding of the geographic distribution of mold incidences and the mold susceptibility of these assemblies, and will communicate this enhanced understanding to builders and energy codes and standards organizations, thereby resulting in improved decisions being made regarding options for retention of envelope energy efficiency and integrity, mitigation of water intrusion, and prevention of mold.

Scientific advancements proposed in this project will not be adequately addressed by competitive or regulated markets. Builders and building contractors are typically small businesses without resources to conduct a research effort of this magnitude and scope. The insurance industry has opted to limit or exclude mold coverage rather than incur large exploratory research expenses. Benefits of the proposed research will primarily accrue to homeowners (and utility ratepayers) through reduced remediation costs and reduced insurance rates, as well as improved indoor environments. The expected research results will also influence future building energy codes and standards. The California Energy Commission PIER funding is a key mechanism for funding such dispersed benefits projects.

Objective

The primary objective of the UIC-ERC work supporting this GTI effort is to provide a relational database linking mold incidences, construction details, and climatic conditions in California. The goal of Task 2 Situation Analysis is to perform a situation analysis of mold incidences in California homes. This situation analysis includes a literature review. The goal of Subtask 2.1 Literature Review is to assemble and evaluate public domain information on problematic and mold resistant residential building materials, assemblies, and construction practices. Efforts under Task 2.1 included:

- Conducting a literature review of research efforts available in the public domain concerning residential building components and moisture and mold.
- As appropriate, interviewing select building researchers, major homebuilders, and other experts in the field regarding current and future housing subsystems, building material selection and construction practices.
- Preparing this document, a Literature Review Summary Report, with a bibliography and key findings from the literature reviews and interviews.

The ultimate objective of Subtask 2.1 is to provide a preliminary set of recommendations identifying moisture intrusion resistant building assemblies and practices for further investigation and application in the Laboratory Evaluation, Demonstration Homes, and Information Product Dissemination tasks.

Process

To accomplish this objective, UIC-ERC conducted a interview process and literature review.

At the outset, the literature survey process was organized by categories under 2 major headings and 15 shared subheadings listed in Table 1 below. The number of reviews under each major heading and subheading is also noted in Table 1.

Table 1. Literature Survey Categories

Major Headings	# Reviews	Shared Subheadings	# Reviews
Building Assemblies	84	Moisture	36
		Mold	2
		Materials	3
		Basement	3
		Crawlspace	2
		Slab	1
		Walls	11
		Vapor Barriers	0
		Windows/Doors	3
Construction Sequencing	1	Roofs	2
		Attics	4
		Plumbing	0
		HVAC	9
		Ventilation	2
		Airtightness	2
		Lighting	1
		Manufactured Housing	4
Totals	85		85

Literature review write-ups were then generally formatted as shown in this example –

Major Grouping: Building Assemblies
Subgrouping: Attics
R4) Rose, William B. Anton TenWolde "Venting of Attics and Cathedral Ceilings", ASHRAE Journal, October, 2002, Pages 26-33.
Problems Encountered: ….
Solutions Found: …

A very brief overview usually preceded the discussion of problems and solutions . Note the reference identification "R4" is keyed to the same notation in the Literature Bibliography in this document. All the actual literature reviews are contained in Appendix B of this document.

The major groupings and subgroupings also form the basis for keyword searches in the literature survey. However, such a literature search was perceived to be too time intensive and much less productive than more targeted and more relevant materials identified by the experts already on the project team and those interviewed in the field. Fortunately, much of the key relevant literature reviewed was already known to the project team, or identified by the expert interviewees, which dramatically reduced the need for a broad based, keyword-driven literature search..

Table 2 on the next page identifies the 8 interviewee categories and the number of interviews in each category. Each interview started with an introduction that identified the California Energy Commission as the project sponsor for research work on mold in California homes, and these interviews as part of an initial project task – a situation analysis. Then the interviewee was informed that we were contacting them as an expert in a given field – "fill in the blank" using the categories in Table 1. A series of questions was then asked to identify building conditions and construction materials and practices most prone to mold growth, as well as innovative construction materials and envelope designs resistant to moisture and mold growth. Often this was best accomplished by simply asking what are the top 3 problems related to moisture in homes, and what are the solutions they have found, or envision, for those problems. This structure formed the basis for the interview write-up format as shown in this typical example –

I6) Building Science Consultant.
Problems Encountered: ….
Solutions Found: …

Note the interviewee identification "I6" is keyed to the interview number notation in Table 2 and the actual interview summaries contained in Appendix A of this document.

Table 2. Interview Summary

Interviewee Category	# of Interviews	Interview #s
Building Science Researcher	2	1,2
Building Science Consultant	3	6,8,9
Building Component Manufacturer	3	3,4,10
Building Standard/Code Official	1	7
Home Builder/Developer	3	11,12,13
Utility Staff Residential Specialist	1	14
Water Damage/Mold Remediator	2	5,16
Mold Specialist/Health Official	1	15
TOTAL	**16**	**in Appendix A**

Major Findings

The interviews with experts in the field provided an up-to-date sampling of the most relevant issues related to moisture intrusion in building assemblies. The (mostly peer reviewed) literature created a supporting foundation of information detailing background on the moisture intrusion issues cited by the experts in the field, as well as other issues.

Interviews

The major water intrusion issues cited in the 16 interviews include:

- Bulk Water --
  Improper lot grading and/or settling create slopes toward foundations and allow water to intrude into slabs, crawlspaces or basements; irrigation systems overspray water and repeatedly wet foundations and walls; and roof downspouts are inadequately separated away from homes and deposit water near foundations instead of to a properly sloped grade.
- Roof Eaves --
  Roof eaves lack sufficient extensions outward and permit rain, especially wind driven rain, to soak exterior porous (brick, stucco, wood, etc.) facades.
- Vapor Barriers --
  Barriers are sometimes incorrectly applied or of the wrong type, depending on climate, and allow moisture to be trapped or build up in walls. Walls need to be able to breathe.
- Window Detailing in Wall and Roof Penetrations --
  - Builders and subcontractors lack sufficient training for proper installation of windows (and flashing).
  - Building codes lack standardized window installation practices.
  - Standards are non-existent for installation of building membranes and flashings with windows.
  - Standards for windows, building membranes, and flashing are outdated (post WW-II ASTM standards) and need to be modernized.
  - Trade organizations for fenestration, building membranes, and flashing are needed to foster these training, standard, and code activities.
- Plumbing --
  - Fittings are not always pressure tested before sealing and can leak undetected for some time behind walls.
  - Piping is often punctured by other trades during construction and can leak undetected for some time behind walls.
  - Alternative, more robust systems are needed to help remedy these plumbing leaks issues.
- Interior Moisture/HVAC --
  - Houses are too tight for natural ventilation to be effective. Mechanical outside air (OA) ventilation is needed.
  - Architects and engineers need to be educated on ventilation issues and mechanical ventilation options.
  - Oriented Strand Board (OSB) often gets wet during construction and then is not adequately dried before wall and roof construction is completed.

    - Some newer paints have much less tolerance to mold growth than paints manufactured 20-25 years ago.
    - DHW heaters, AC coils/drain pans, and ductwork, are placed in attics where leaks can go unnoticed for some time until after substantial damage is done.
    - Baths and kitchens do not have properly sized exhaust fans that run until moisture levels are reduced to desired humidity levels. Fan operation needs to be automated (based on humidity level) to remove the human factor. Most of these fans are too noisy and people are annoyed and limit their operation.
    - Wet spray cellulose, if used, Is not allowed to dry sufficiently. Moisture content needs to be checked before closing drywall.
    - Moisture content in wood framing is often to high before closing in the walls. Moisture content needs to be checked before closing drywall and should not be higher than 19%.
- Miscellaneous
    - A homeowners' manual needs to be developed that would address some of the maintenance issues that could prevent mold incidences over the life of a house.
    - A builder's manual needs to be developed that offers a "systems approach" to ensuring quality and managing risk during construction. For example, utilizing a series of checkpoints established by extensive litigation and failure analysis background, specially trained inspectors can check for specific, known anomalies in the building assemblies at greatest risk of water damage and mold formation.
    - Construction sequencing is a clear issue with poor scheduling leading to unprotected building materials getting soaked with rain/snow on the job site.
    - Elastomeric paints for stucco to limit cracking and water intrusion need to be utilized.

Literature

A total of 85 literature reviews were completed based on extensive input from the project team and expert interviewees. A survey was also conducted using key words on a variety of search engines, including major commercial and university library based search engines. The following additional keywords to Table 1 were included in, but not limited to, the search: moisture intrusion, residential, homes, and California. The search produced many additional pieces of literature from a variety of sources from trade journals and magazines to product and material organizations.

Some literature provided the scientific and engineering basis for moisture migration in buildings, and ultimately the understanding to manage moisture in homes

Many of the pieces of literature cited established the methods by which moisture travels:

- Pressure differential
- Temperature differential
- Capillary action

- Spills/leaks
- Diffusion

Other literature detailed the points at which traveling moisture intrudes into buildings and its assemblies. The following moisture intrusion problem areas were mentioned frequently in the literature. Common moisture intrusion points are:

- Penetrations in walls and roofs: windows, doors, skylights, piping through walls, ductwork through walls and ceilings
- Roofs with improper installation of flashing, or gutters not working properly
- Surface or ground water pooling from improper grading, irrigation system overspray, and improper placement of downspouts.
- Interior moisture buildup due to over crowding, improper exhaust venting (bathrooms, kitchen, and laundry), too low of a cooling temperature set point, inadequate removal of moisture (insufficient dehumidification).
- Attic/crawlspace moisture from leaky HVAC ducts, condensation on cooler surfaces, improper ventilation of attic/crawl spaces.
- Improperly installed vapor and air barriers. Proper placement of air barriers is important to allow building assemblies to dry out.
- Infiltration of moist air when leaky HVAC ducts cause pressure differentials, leading to outside air being drawn in to building, and oversized air conditioning equipment leading to short cycling that reduces the AC equipment ability to dehumidify.

Potential solutions that were cited for moisture problems are:

- Use materials that are not prone to moisture build-up and mold formation: no vinyl wallpaper, etc.
- Provide proper air barrier placement for the building assembly to dry out.
- Provide eaves with at least 18 inches overhang, and do not start siding within 8 inches of the ground/soil.
- Increase the cooling set point temperature, and allow the air to flow around the entire space (well mixed conditions). Furniture can block airflow to corners, leading to cold spots and moisture condensation on cooler, dark surfaces. Provide supplemental dehumidification in addition to air conditioning.
- Make sure that flashing is properly installed everywhere, particularly at doors and windows.
- Venting of crawlspaces depends on climate: hot humid climates do not necessarily benefit from natural ventilation of crawlspaces.

There have been several field studies of moisture and mold in manufactured housing, but not as much for single-family residences, especially in warmer climates dealing with summer cooling moisture problems. Future researchers are encouraged to update this literature survey by searching for the latest literature related to field work on moisture problems in single family residences, especially in cooling dominated locations. The existing field data for manufactured homes, and single family homes in heating dominated climates, is best summarized in the 1994 ASTM Manual 18 on Moisture Control in Buildings [R84] from the literature survey.

In addition, future researchers are also encouraged to conduct additional interviews regarding the following issues and their impact on moisture problems in houses:

- complicated home construction (especially roof) design.
- larger and less skilled construction labor pool.
- duct leakage issues.
- vapor barrier types and locations.
- old vs. new -- leaky vs. tight -- energy efficient vs. standard -- home design and the potential for water retention and mold growth.

Recommendations

Laboratory Evaluations and Field Demonstrations

The following list of ten areas for study and evaluation in later laboratory and field activities has been culled from the interviews and literature:

1. Upgrading window (and door) installation techniques, standards and codes to foster proper flashing, etc.
2. Improving plumbing systems and installation practices to ensure pressure testing before operation, eliminate punctures by other trades, etc.
3. Changing HVAC and DHW placements from attics to utility closets, etc. And where practical move ductwork from unconditioned to conditioned spaces.
4. Studying role of tight versus loose construction in trapping intruding moisture, providing drying potential, and creating environment for mold growth.
5. Finding alternatives to, or enhanced means of water intrusion protection for, hygroscopic building materials such as OSB in wall and roof assemblies (and also make sure such materials as OSB are sufficiently dry before finishing interior or exterior walls). Likewise, finding alternatives to mold food sources, e.g., substitute fiberglass paper for cellulose on drywall.
6. Evaluating proper placement of vapor barriers in wall assemblies, including smart vapor barriers, to inhibit water vapor transport but allow drying under saturated air conditions and new home humidity pulldown.
7. Implementing viable drainage plane techniques for porous exterior wall cladding. (Water intrusion needs to be limited. The City of Seattle has been promoting the use of the rain screen wall system since 1999. In the rain screen wall, exterior cladding is set off ¾ inch from the building wrap and vented top and bottom to provide a drainage plane away from interior wall elements. They also recommend membrane products as a “smart” vapor barrier.)
8. Extending roof eaves to limit soaking of building exterior wall surfaces. Also evaluate the role of more complex roof lines on water intrusion.
9. Promoting proper grading, along with sufficient roof downspout and irrigation spray separation from foundations and walls
10. Producing a homeowners’ manual on methods to maintain a residence to prevent moisture intrusion and mold growth. Likewise, produce a builders manual to check during construction for known anomalies leading to water intrusion.

Future Literature Reviews and Interviews

Future researchers are encouraged to update this literature survey by searching for the latest literature related to field work on moisture problems in single family residences, especially in cooling dominated locations. In addition, future researchers are also encouraged to conduct additional interviews regarding the following issues and their impact on moisture problems in houses: complicated home construction (especially roof) design; larger and less skilled construction labor pool; duct leakage issues; vapor barrier types and locations; and old vs. new -- loose vs. tight -- energy efficient vs. standard -- home design and the potential for water retention and mold growth.

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Appendix A – Interview Summaries

I1) Building Science Researcher

Problems Encountered: Moisture problems are climate dependent. In hot humid climate, there is an increase in mold incidences. In dry climates, there are virtually no mold incidences.

In CA, outdoor air is sufficiently dry most of the year. Most mold issues likely come from bulk water intrusion. However, internally generated moisture requires attention (elimination) so high indoor humidity levels are not encountered.

Solutions Found: See ASHRAE Standard 62.2 (Residential), which is available now, for exhaust fan recommendations to vent internally generated moisture.

Exhaust fans:
Residential standard 50cfm for each bath, and
100cfm with range hood, or 5 ACH without range hood.
Net house exhaust less than 7.5cfm/sq.ft. because, we do not want:

- Back drafting of appliances
- Moist air into walls in hot humid climes
- In radon area, radon coming out of soil

Other ventilation issues:

Thermal conditioning equipment should not be in unconditioned zone(s). For example:

- Ducts passing through hot/cold attic
- Furnaces in garages (IAQ issues-all ducts leak. All AHUs leak)

Be very aware of overly tight underventilated homes. They have the greatest possibility of indoor moisture issues that can turn into a mold problem.

I2) Building Science Researcher

This researcher's primary main knowledge base is for the Florida climate, but comments can be applied to residential homes.

Problems Encountered: Based on expertise in HVAC and ductwork, the researcher sees the main problems for moisture in homes as excessive ventilation, including uncontrolled airflows, allowing humid air into the building construction. Additionally, air conditioning systems that do not dehumidify adequately can exacerbate the moisture problems when cooling, due to resulting high indoor humidity levels and condensation on cooler surfaces. Setting lower thermostat temperatures (below 70F) during the cooling season cause additional moisture/condensation problems.

The venting of attics, particularly in Florida's or other humid climates, can cause moisture problems. As basements are not common in Florida, the ductwork is placed in the attic. When the attic is then vented, the ductwork tends to "sweat" and condensation that forms can then drip on to ceilings below. Also, duct leakage in another problem that can lead to moisture problems, as does vinyl wall paper, which acts as an additional vapor barrier, allowing more moisture to condense.

Solutions Found: By maintaining positive pressure in a home, causing the air to flow from inside to outside -- thereby not sucking the humid, moist air from the outside into the building construction -- some moisture problems can be alleviated. The selection and controlling of cooling systems so that they dehumidify the air sufficiently, and before it enters the building, reduces the moisture level inside a building.

A solution to the attic issues includes not venting attic spaces, so that the roof deck becomes the primary air barrier. By using spray foam under the roof deck you then can locate the ductwork in the attic but inside air and thermal boundary. This not only reduces the chance for condensation to form on the ducts and drip to ceilings below, but also reduces the ventilation from infiltration, thereby reducing the unplanned humidity load. The same can be applied to crawl spaces, though they are not as wide spread in Florida.

I3) Building Component Manufacturer

Problems Encountered: Moisture problems usually occur in blown insulation systems because they are not allowed to dry adequately. Often the insulation will dry after the wall is finished, however, high moisture in the wall cavity is inherently problematic.

In colder climates, the opportunity for wall cavity water vapor issues is greater. In coldest climes (mountains) use of fiberglass, not cellulose, insulation is recommended. However, these moisture problems are minimal compared to most of the moisture problems caused by bulk water intrusion.

Solutions Found: The Cellulose Insulation Manufacturers Association (CIMA) states that the wall cavity should be open as long as necessary to dry. Since drywall contractors are usually on site 24-48 hours after cellulose installation, the use of an internal vapor barrier is not recommended to allow for continued drying in the wall cavity.

Other problems: Oriented Strand Board (OSB) typically used nationwide for exterior sheathing. Builders use OSB for nearly 100 percent of construction. It soaks up water and is difficult to dry after walls are completed. Make sure walls are dry before finishing interior or exterior.

Final note: Lathe and plaster is better than gypsum board with respect to mold growth. Older homes are typically more mold free for this reason.

I4) Building Component Manufacturer

Problems Encountered: Plumbing is at the top of list of moisture problems in homes. This includes primarily plumbing leaks and connection issues that usually occur in bathroom and kitchen locations. Another problem for moisture in buildings is EIFS (Exterior Insulation Finishing System) which has leakage through the exterior system into walls. Moisture due to improper moisture control in foundation systems – slabs and crawl spaces -- is a third major problem.

Solutions Found: Solutions to moisture problems include builders and architects thinking through the design systems, and creating utility systems that are readily accessible. It is difficult to check for problems when they are not easily accessible. It can be very costly to have to rip out a wall in order to fix a problem within the wall construction. Accessible hatches would allow for easy access to utilities and the like.

EIFS-barrier type wall constructions should be banned in general, and replaced with water managed systems, i.e., walls with drainage planes or gaps. Proper flashing also reduces moisture problems in walls. EIFS has rapid deterioration of the wall construction and is a good incubator for mold. A solution with respect to the moisture through crawl spaces and foundations is ground cover beneath the slab or over the crawl space. Builders cannot rely on the stucco as the water barrier, and it is near impossible to seal around openings and fenestration with this wall type as well.

In the past, foundation systems used sand over a vapor barrier, not allowing moisture to evaporate, so moisture tended to pool causing problems. Since diffusion is a slow process, small holes in the vapor barrier is not a bad thing, and does allow some breathability. The vapor barrier does not have to be seamless. Crawl spaces no not need to be ventilated, as previously thought, but must have ground cover.

In general, there also needs to be some change in the ways builders and designers think about constructing buildings. Climates should have a significant impact on the way a building is constructed, and select constructions and materials that are appropriate for the given climate. Also the location of the vapor barrier and treating it separate from the air barrier is important. Controlling the airflow is an important issue that must be addressed. Buildings need to recognize that they must have an air barrier to reduce gross air infiltration, and again determine what is appropriate for climate. Historically much of the building construction research was done in the northern climate and applied to southern climates, though the conditions are very different.

There needs to be the proper execution of details. This includes the proper installation of flashing and lapping building paper appropriately. In general things need to be looked at as system issues, not as single elements.

Possible innovative construction materials and envelope designs include water managed systems and drainage plane. Pressure equalized exterior walls are a newly emerging technique that is still highly debated, and particularly applicable to high rise buildings. The elimination of EIFS barrier type wall construction is another recommendation, as this has rapid deterioration when moisture enters, and is a good incubator for mold growth. The application of smart vapor retarders or barriers, which

allows the porosity to increase with increased relative humidity, can improve the reduction of moisture in walls. Kraft faced insulation that has been in use for years also acts similarly to these smart vapor barriers -- a nylon membrane system is currently available for commercial use. Use properly installed flashing rather than caulk.

It is important to separate out the myth. This includes weeding out imitators to products that become popular, but do not function as well as the original. There is a need of information available to consumers, builders, and designers to sort the good products from the bad. The concept of grouping utilities together so that they are more accessible in general, such as is used with manufactured housing, is important to be able to access problems more quickly, and at a lower cost. Also humidity and moisture sensors embedded in walls can assist in detecting moisture problems at their early stages. Though expensive to install throughout a building, installation in key locations that are prone to moisture problems is a start. This would assist in alerting homeowners to mold and moisture issues at early stages, before rot and mold growth can infiltrate the building.

Education is another important aspect of improving construction methods and reducing moisture problems. Possible solutions include homeowner operation and maintenance manuals, even long term warranties, such as the automotive industry has for extended coverage. Manuals would detail when and what maintenance needed to be done, by owner or by professional, as well as educating the homeowners. Also, some builders have websites that include warranty and maintenance issues, including newsletters that keep the owner up to date for maintenance.

I5) Water Damage/Mold Remediator

Problems Encountered: Top three types of moisture in homes included envelope leaks (roofs, walls, etc), condensation issues (moisture condensing) and moisture penetration through slabs.

Solutions Found: The top three types of solutions include fixing the water problem, remove fungal growth, and clean up settled spores. By substituting lathe and plaster wall finishing for gypsum board, moisture intrusion is reduced, as lathe and plaster is more mold resistant, but more costly.

Internal moisture generation, particularly in crowded dwellings, leads to additional condensation issues. By installing draw fans that run automatically, with humidistat controls, this problem can be reduced.

Avoiding certain types of envelope systems is an additional method to resist mold growth -- you must allow the intruding moisture to get out. The use of envelope systems with water drainage planes or smart vapor barriers can assist in moisture removal from wall constructions. Exterior Insulation Finish Systems (EIFS) offer an alternative to traditional claddings such as wood, brick and stone, and offer a variety of finishes, including fine and rough sand, sculptured, and stone, and is resistant to mold and fungal growth, <u>if installed properly and used with water drainage planes</u>.

Avoid getting liquid water into envelopes through grading issues, allowing the water to be carried away with water diversion systems.

Lowest on the list are plumbing issues -- be sure to test the plumbing system using pressure testing for tightness after the building is complete.

I6) Building Science Consultant

Problems Encountered: Proper window installation and the relationship of windows to weather resistant barriers can cause significant mold issues. Installers need to be formally educated and held accountable for proper window installs. Builders need to be educated so they can determine which weather resistant barriers to use in different climates. The builders do not understand or perhaps care about weather resistant barriers, permeability, material properties, etc. Currently, builders would use the same building plan in Maine as in Washington state. "Builders shouldn't be building homes the way they did 40 years ago."

Solutions Found: This consultant believes there are 18 different climatic zones in the U.S. and weather resistant barriers need to be selected based on climate and properly installed especially at planned envelope openings. They (ORNL et al) have developed a program called WUFI that integrates weather data collected from NOAA over the past 50 years, with known building science for wall construction. The WUFI weather data is precise to locations (literally thousands of them) that can be utilized individually by longitude and latitude or grouped (in this consultant's opinion) into 18 different climate zones. The consultant is aware that the state of California has an intricate weather reporting system because of California's heavy involvement in agriculture. This data is also supplied to NOAA, but the state of California primarily has been supplying it. This could be the best weather reporting in the country. There is no question that California contains 100-degree spreads in temperature and large swings in humidity. It would be fair to say that there are at least 8 different climate zones in California. If you want more information on the WUFI program, go to ORNL's web site and there is a link on there for the WUFI program.

The critical industry needs to reduce the number of mold incidences are:

1. Education, education, and more education of builders and subcontractors.
2. Reworking of building codes -- standards for membranes and flashings.
3. Modernize windows, building membranes, and flashing standards and practices from post WW-II -- ASTM is outdated.
4. Create trade organizations for fenestration, building membranes and flashing.

The consultant believes that eliminating moisture is the key to eliminating mold. Windows leak and that will not change. If the leaking moisture has a clearly defined path for drainage, mold incidences will be mitigated.

The consultant is currently working with the National Institute of Building Science on a series of mold mitigation protocols for private groups. He believes the adoption of said protocols is the key to eliminating mold in residential construction. The current protocols might be available for the public by January 2005.

I7) Building Standard/Code Official

Problems Encountered: Mold is caused by poor building moisture management. Moisture problems occur both on the exterior and interior of residences. On the exterior, leaks at windows and wall penetrations (no flashing or caulking) are worst. Windows-ASTM test does not test typical failure points of windows (miter points, drain channels, etc.). On the interior, inadequate ventilation systems (exhaust) limit moisture removal. Use of such systems is the issue not necessarily sizing or design. Since fans are noisy, they don't get used. If they are used, they do not remain "on" long enough to remove all the moisture from the interior (e.g. bathrooms).

Solutions Found: On the exterior, eliminate water ingress by using construction technique such as the rain screen wall. Our city has been promoting the use of a rain screen wall system since 1999. Exterior cladding is set off ¾ inch from building wrap and vented top and bottom. They also recommend membrane products. Use documentation such as the Northwest Wall and Ceiling Bureau guideline for installing windows. There is a lack of understanding of how exterior wall components come together. Our building department recommends 2 layers of weather resistant exterior wrap – one layer of air barrier and one layer of building paper, or two layers of building paper to facilitate drainage off of exterior wall.

On the interior, put in continuous mechanical ventilation systems with occupancy sensors so they will always be "on" and eliminating moisture when needed. Fans should be quiet.

Other references:

www.hpo.bc.ca talks about rainscreen with links to other research.
www.wsu.edu/energy
www.buildingscience.com

I8) Building Science Consultant

Problems Encountered/Solutions Found: The consultant stated that interior moisture build up is a big problem in more humid (Gulf Coast versus California Coast) coastal climates. Code does not require use of an outdoor air (OA) intake. Moisture builds up in houses at night, and will condense out onto windows, panes, etc. Houses are too tight and need OA intake to dry interior conditions.

More education is needed all around from engineers and architects to builders and sub contractors. Most builders are using building techniques that are not necessarily scientifically based. This leads to problematic homes with respect to mold.

Building components such as OSB are intolerant to moisture. Also, some newer paints have much less tolerance to mold growth than paints manufactured 20-25 years ago. Paint manufacturers have eliminated heavy metals, but now might need to introduce an antimicrobial.

Do not place ductwork in attics. Leakage rates of 5-10 percent are considered good, most leakage rates are larger. Leakage in attics creates negative pressure, which will bring moisture into wall cavities and into the interior spaces through all imperfections in the envelope.

I9) Building Science Consultant

Problems Encountered:

- Bulk water intrusion from outdoors
- Issues with vapor barriers (none, incorrectly applied, wrong barrier depending on climate)
- Window detailing in penetrations.
    - Window design issues
    - Workmanship issues
- Construction sequencing is a clear issue-poor scheduling leads to building materials getting soaked.
- Bathroom or utility room exhausting to attic, not outdoors.
- Maintenance issues.

Solutions Found:

- Window designers/installers need to work together to guarantee water is shed from window. Better quality control. For example, owners don't want to pay for inspector to determine if caulk is installed correctly.
- Vapor barrier generally should be on the hottest surface. Vapor barrier on exterior (hot, humid climates). Otherwise, interior.
- Vapor barriers should be continuous with no tears or perforations.
- Construction sequencing -protect materials while on-site keep dry. Schedule construction appropriately for climate type.
- General maintenance of property (caulking needs to be replaced, tuck pointing completed, etc.)
- Could use an O&M manual for homeowners.

Sources of other info:
AQS Air Quality Sciences http://www.aqs.com/index.asp

I10) Building Component Manufacturer

The manufacturer stated that both exterior and interior moisture is a problem with respect to mold. These are both climate dependent and this cannot be ignored. That is, you cannot address construction sequencing the same way in the desert as you do in the coastal climes (desert construction is more simple since moisture is much less of a problem).

Problems Encountered/Solutions Found:

Exterior moisture –

Exterior water must be prevented from entering the home. Big issues are improper installations of windows/flashing, improper selection of house wraps, not letting sheathing dry prior to starting interior construction. Windows and flashing should be installed in accordance with specifications such as stated by the American Architectural Manufacturers Association www.AAMAnet.org.

Proper building wrap should also be selected based on climate. Some house wraps are semi permeable breathable materials (moisture can pass through). Other wraps are not breathable but can be mechanically perforated to allow moisture transfer. The most advanced wraps are membranes that transfer moisture equally well in both primary directions. If moisture gets in, it can get out via draining or reverse permeability. By contrast, the simplest building wrap is inexpensive 15-30# felt paper wrap with a low (1.0-4.0) permeance factor for water transfer. Climate determines the optimal permeance for the house wrap.

Moisture breaks are critical for masonry, masonry façade, foundation walls and slabs. Polyethylene sheeting should be used under slabs as moisture break.

Interior moisture (humid or rainy climates only) --

Building materials may take on water (rain) during the construction process. Those materials need to dry before closing up the house. Lumber moisture content is critical. Never start interior work before house is under roof and shingled. Moisture content in wood should not be higher than 19% (if higher likelihood to grow mold in wood/walls is much greater).

Wet spray cellulose, if used, must be allowed to dry (check moisture content before closing drywall).

Removing point source generation is critical. Ventilation requirements should be matched for size/occupancy of house. Exhaust fans must be used.

I11) Home Builder/Developer

Problems Encountered/Solutions Found: This homebuilder emphatically stated that their homes have never experienced a mold occurrence in any of their construction. The builder attributes that to their impressive continuous quality control program that evaluates construction practices from excavation through to obtaining the certificate of occupancy.

The builder stated that water intrusion is the most costly and problematic new construction issue in California. He believes improper grading and poorly installed windows and flashings to be the biggest contributor to exterior water intrusion. Lack of education opportunities and quality control were cited as issues exacerbating water intrusion. Windows are installed per the A-drawings, which do not necessarily have adequate detail for the subcontractor to complete the job properly. There is virtually no quality control in the field. There is too much emphasis on completing projects faster and faster. Very simply, no water equals no mold growth opportunity. But if water does intrude, products containing antimicrobials can be used to insure against mold growth within the home.

Additional contacts -- the California Industry Association should have references and periodical with respect to mold intrusion in California homes.

Products/services for follow up research:

- Antimicrobial protection of building products.
- A "systems approach" to ensuring quality and managing risk during home construction utilizing a series of checkpoints established by extensive litigation and failure analysis background. Trained inspectors can check for specific, known anomalies in the building assemblies at greatest risk of water damage and mold formation.

I12) Home Builder/Developer

Problems Encountered/Solutions Found: Moisture intrusion and subsequent mold growth is not a big problem in southern California. This company has had two mold incidences both due to plumbing problems. Nails can be driven into a piece of copper pipe forming a seal that degrades over time causing a leak that saturates drywall. Also, pinhole leaks can occur. The builder is a big proponent of flexible (crosslinked polyethylene) plumbing systems to help remedy these plumbing issues, though it is more costly than a copper tubing installation.

According to the builder, these alternative plumbing systems rates high with installers and engineers due to its:

- Flexibility, which eliminates many of the joints necessary with copper pipe.
- Installation options, including traditional branch as well as manifold piping.
- Corrosion resistance to harsh conditions in water and soil - no corrosion, pitting or scaling means happy customers and less call-backs.

I13) Home Builder/Developer

Problems Encountered: The builder stated that mold is an issue more along the coast than inland. Problem areas include plumbing leaks, water intrusion due to heavy rains (rare), and improper maintenance of the homeowner. For example, when caulking fails in the bathroom, the average homeowner does not address this issue, creating an opportunity for mold. Because of this, the builder feels problems due to interior water is more prevalent.

Solutions Found: Educate subcontractors. Plumbing leaks occur most after the finished interior wall is in place. Of course, double check for leaks in the plumbing system prior to finishing walls. Mold/mildew resistant paint can be used on the interior and exterior. On stucco finishes, they use an elastomeric paint for moisture soundness. This paint has a twenty five year life if you install it properly (requires a certain thickness). Typically installed via spray and back rolling.

Rubberized coating is used for flat roofs and parapet walls.

Finally, the builder wants to see an owners manuals for home owners that would address some of the maintenance issues that could prevent mold incidences.

I14) Utility Staff Residential Specialist

Problems Encountered/Solutions Found: In eight plus years, this utility specialist has not experienced mold growth in California homes. However, it is problematic that construction during the rainy season is typically completed without regard to letting walls/roofs/floors dry completely before finishing. This is standard practice throughout southern California.

I15) Mold Specialist/Health Official

Problems Encountered:

- Water intrusion due to construction/design defects
- Problems with internal humidity (limited moisture removal)
- Problems with rental property (no or deferred maintenance).

From public health perspective the primary concern is with water intrusion (leakage), mainly in schools. The maintenance practices in schools are suspect.

Solutions Found:

Information services for people suffering from heath-related problems allegedly caused by IAQ problems. See www.cal-iaq.org for IAQ info sheets. Speakers are also invited to builders/architects symposia.

I16) Water Damage/Mold Remediator

Problems Encountered/Solutions Found:
This remediator stated the major problems causing moisture intrusion/mold growth are: irrigation, drainage, and plumbing issues and miscellaneous building considerations.

Irrigation Issues -- Homes on flat property using sprinklers to irrigate can entrain significant moisture to the home. Sprinkler heads are often mounted too close to walls thereby wetting the walls significantly 3-5 times a week. In areas of significant shading, this moisture cannot dry. The moisture can be wicked into the wall cavity and may not be able to properly drain because “weep screeds” are often blocked or buried altogether. When this happens, moisture backs up in the wall cavity and decays vapor barriers. Then moisture impregnates drywall. If the vapor barrier is compromised or dissolves altogether, there is no protection for the interior wall. This protection cannot be regained until the stucco is removed and the vapor barrier reinstalled (he has completed this once or twice). A continuous vapor barrier is key. Water in cavity yields mold on paper, mold on drywall,

Drainage Issues -- In many instances, graded land will drain directly into the side of a house or perhaps onto a roof. This is an opportunity for significant wetting of walls/roofs not only by weather, but by run off of irrigation systems. Better site plan grading is needed. Aesthetics should not be the determining factor for home siting and plot grading.

Plumbing Issues-- (supply, waste, and roof penetrations) Test for leaks under pressure. Be cognizant of piercing waste lines with nails or screws. Roof penetrations are difficult to test for leaks since there is little precipitation except for November through January (in southern California. However, as a general rule, flashing is often incorrectly installed on roofs. Problems may not appear for years. Do not place condensation drain lines in a wall cavity. Education of the general contractor and subcontractors is sorely needed.

Building construction considerations:

- Water heaters should not be put in attics. If they must, drain pan on water heaters must be properly sized (they are usually undersized).
- Condensation in bathrooms needs to be controlled by proper exhaust fans. There should be emphasis on this in local codes for size and placement of fans.
- No vinyl wallpaper anywhere in proximity to baths/kitchens – it is a haven for mold growth. No carpets in bath or kitchens.
- Big difference between lathe and plaster vs. drywall. Old houses are inherently mold resistance because of their plaster and lathe walls. Drywall has paper on back -- perfect food for mold.
- Cabinetry should use solid wood, if possible. Compressed wood (engineered wood product) is compressed particle board. When wetted, they expand and burst providing a moist environment and source of food for potential mold.

Appendix B – Literature Reviews

Major Grouping: Building Assemblies
Subgrouping: Moisture

R1) Lstiburek, Joseph "Investigating and Diagnosing Moisture Problems", ASHRAE Journal, December, 2002, Pages 36-41.

This article examines the problems of moisture in buildings, and provides rules of thumb to alleviate and avoid these water issues. The four forms of water are described: solid, liquid, vapor and absorbed. Also described are the various ways that moisture moves. These descriptive parameters are then applied to buildings.

Problems Encountered: In building construction, moisture is driven by concentration gradients (moving from more to less), pressure gradients (areas of higher to lower), thermal gradients (from warm to cold), gravity, and material porosity (from more to less along concentration gradients). Each of these alone, or a combination of these factors, can drive moisture into wall constructions, leading to water issues and building problems. Rules presented in the article to circumvent these factors include "1) never install a vapor barrier on the inside of a wall assembly that has a moisture reservoir cladding and a vapor permeable combination of sheathing and building paper, 2) always vent claddings, and 3) never suck on the exterior building enclosure with the mechanical system."

Groundwater is an additional means for water to enter a wall assembly. Water from rain and watering plants are common ways for moisture to make its way into building construction through porous concrete and capillary action. Using a sand layer between the polyethylene vapor barrier and foundation does not allow the moisture anywhere to go except upwards into the wall construction. By reducing the wetness of soil around the foundation, using capillary breaks, and not using concrete on top of a sand layer over a polyethylene sheet, moisture problems caused by groundwater can be resolved.

Solutions Found: As noted above for walls and slabs, by understanding how water moves in buildings, and knowing the behavior of water in its various forms, building owners, designers, and contractors can better prevent moisture problems.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R2) Brennan, Terry Joseph Lstiburek "Unplanned Airflows and Moisture Problems", ASHRAE Journal, November, 2002, Pages 44-49.

This article approached buildings as a network of "chambers connected by air leaks". Pressure differences cause air to move from one chamber to another throughout the building, with the amount of air depending on both the pressure difference and the size of opening or hole. Chamber types include rooms, hallways, stud walls, plenums, soffits, and shafts to name a few.

Problems Encountered: Unplanned airflows can have positive or negative impact on a building and its occupants; positive impacts include providing ventilation to rooms that would otherwise not have ventilation. However, these same unplanned airflows can also cause air quality, thermal comfort, unnecessary energy use and moisture problems, particularly in building envelope cavities. Several studies have been conducted to understand planned versus unplanned airflows in buildings, concluding that repairing unplanned airflows can reduce energy usage, duckwork was leakier than SMACNA standards, certain types of ceilings were leakier than others, and often buildings had relatively high ventilation rates. It was also determined that accidental airflows were often a "significant fraction of the total ventilation rate", which caused problems with comfort, energy usage and moisture. The magnitude and combination of these problems could vary with climate and season.

Unplanned airflows often lead to condensation problems caused by accidental humidification, particularly during the cooling season, when warm humid air is outside, while building interiors are air-conditioned. In addition, accidental depressurization can be a driving force, causing the same moisture problems, as outdoor air is then drawn through leaks in the exterior building envelope. In this case, the most common condensing surface is "the backside of an interior vapor retarder or gypsum board". Depressurization is caused by several things, including inappropriate mechanical design for a given climate, clogged filters, or the continuous operation of toilet and mechanical room exhausts when the main dampers are closed at night. Additionally, holes due to gaps around pipes, ducts and conduit can cause leakage from building cavities into the plenum.

Solutions Found: Heating and cooling season dynamics have several important differences, including the moisture sources and location of chilled surfaces, causing change of airflow direction and excess internal moisture due to cold dry outside air and dehumidified ventilation air. Three main rules for preventing moisture problems provided by the authors include making certain that all airflows are planned, building assemblies are resistant to moisture problems, ducts, plenums, connections and envelopes are well sealed, meeting tightness specifications, and buildings are pressurized during hot weather, and neutral to slightly depressurized during cold weather. It is likely that at some point wall cavities will be come wet, so the authors recommend that walls are designed to easily dry, and that materials that are not sensitive to moisture be placed in areas prone to get wet. This includes using new gypsum boards covered with fiberglass fabric, and avoiding more than one vapor

retarder in an assembly. By planning airflow direction, designing for water vapor migration, and using constructions that dry easily, many moisture problems can be avoided.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R3) Straube, John F. “Moisture in Buildings”, ASHRAE Journal, January, 2002, Pages 15-19.

This article describes common sources and movement processes for moisture in buildings and potential means to reduce their impact.

Problems Encountered: Moisture causes much deterioration in areas from corrosion of metal components, deterioration of materials, to the growth of biological forms such as mold. There are four conditions that need to be satisfied in order for moisture problems to occur; an available source, a path to travel, a driving force and materials that are prone to damage. By eliminating any one of these conditions, moisture problems can be avoided, however the authors state that it is “practically impossible to remove all moisture sources, create buildings with no imperfections, remove all driving forces,” and uneconomical to use only moisture inhibiting materials. However, by good design, assembly and material choices, the risk for moisture problems can be reduced.

Solutions Found: Common control strategies for moisture include “increasing the airtightness and vapor resistance of the enclosure”, which reduces the amount of rain water that can enter a building construction. A better solution provided by the authors is increasing the drying potential and storage capacity in building assemblies, as it is difficult to create perfect building construction, so some moisture intrusion will occur. Additionally, allowing a building’s tolerance to moisture through “intelligent design of building location, orientation, geometry, HVAC design” to name a few is a better approach.

In buildings the four main sources of water are liquid, vapor, groundwater (liquid and vapor in soil), and moisture within materials. Only a small amount of leakage is required to cause major problems in buildings, and can be transported by means of vapor diffusion, vapor convection, capillary movement, gravity flow, or a combination of these. There are potential solutions offered by the author for each of these issues. For sources of water, design engineers should “investigate specific processes in detail” in order to determine vapor production, both average and peak. Using a combination of crushed stone and vapor barriers near exterior or below grade assemblies allows vapor diffusion and acts as a capillary break. Controlling vapor convection through the sealing of all ducts, controlling the pressure of a building, and proper installation of HVAC components assists with eliminating convective moisture transport. By installing capillary flow barriers, such as a small air gap or non-porous materials, this transport mechanism can also be reduced or eliminated, while flashing is a good example of controlling gravity flow by redirecting water flows to the exterior of a building.

By combining the above methods of managing or eliminating moisture in building assemblies, reducing the strength of the moisture source and encouraging drying, many moisture driven problems can be removed or reduced.

Major Grouping: Building Assemblies
Subgrouping: Attics

R4) Rose, William B. Anton TenWolde "Venting of Attics and Cathedral Ceilings", ASHRAE Journal, October, 2002, Pages 26-33.

This article reviews the ventilation of attics and cathedral ceilings as past construction practices, and presents a variety of studies that prove or disprove these established practices. Often attic ventilation has been used to control moisture in these spaces, and the lack of ventilation of attics has been blamed for a variety of problems. The authors present reasons for examining the particular climate in the use of attic and cathedral ventilation.

Problems Encountered: In cold inland climates, where many of the original studies focused, it was found that "higher moisture conditions in the attic corresponded to higher humidity conditions in the living space", and concluded that control of indoor humidity could effectively reduce condensation in both roofs and walls. It was thought that ceiling vapor retarders were effective in reducing attic moisture in early studies, but later determined that it was air infiltration through the ceiling that caused much of the condensation. Further, it was thought that using an airflow retarder rather than a vapor retarder would reduce the moisture in attics. For cold climates, using foam insulation applied directly to the underside of sheathing for roofs, and sealed carefully, then venting the attic space is not required, as is the case when the foam or structural insulated panels are installed on top of the roof deck. For cold climates, the most effective measures to reduce moisture in attics presented by the authors are: indoor humidity control, airtight ceilings, and attic ventilation. Cathedral ceilings are more prone to moisture damage due to the individual rafter cavities created. This can be alleviated by the installation of effective soffit and ridge ventilation to each individual cavity, though a difficult task given the geometry of cathedral ceilings.

For wet, cold coastal climates, the outside air is humid, and can be carried into the attic through ventilation, and can be a major source of moisture in this space. Higher ventilation rates in the attic can lead to higher moisture in the sheathing of the roof. So in general, attics in cold, wet coastal climates should remain unvented, as long as the indoor humidity is controlled. As for hot climates, both humid and dry, attic ventilation seems to be unwarranted. In hot, humid climates, moisture content in the outside air is much higher than the interior conditions, where dehumidifiers are often used. Venting attics would increase the moisture in the attic space. For hot, dry climates, there is no reason to vent the attic space for controlling moisture.

Though attic ventilation has often been used for minimizing ice dams, there are some thoughts that better insulation and ventilation of ceilings and attics would reduce the occurrence of ice dams. There is a window of temperature conditions that lead to ice dams; keeping the attic below freezing when outdoor temperatures are 22F. The amount of snow and the amount of insulation in the ceiling are related to the need for ventilation, but all roofs need to be ventilated to avoid ice dams (in appropriate climates).

Attic ventilation was also linked to the deterioration of shingles as recently as the 1980s, though now it has been shown that ventilation “is a minor factor in the determination of shingle temperature”, and that it is more the climate, roof angle and color of shingles that affect shingle temperature and therefore shingle life.

Solutions Found: The authors provide additional studies that show that attic ventilation has little to no effect on the amount of energy that a house used for cooling, and conclude that other factors, including increased insulation in the attic or walls, and proper location of windows and overhangs are better ways to conserve energy year round. They also recommend that cooling ducts not be located in the attic, where leaks in ducts can cause pressure issues, condensation, and additional higher cooling loads. In general, the authors agree that attic ventilation is appropriate and beneficial in some climates and circumstances, and should be a part of a larger range of control strategies for moisture in buildings. Specifically, the authors recommend: indoor humidity control, minimization of heat sources in attic spaces, venting of attics and cathedral ceilings in cold and mixed climates, and appropriate use of ventilation in other climates.

Major Grouping: Construction Sequencing
Subgrouping: Moisture

R5) Harriman III, Lewis G. Donald Schnell, Mark Fowler "Preventing Mold by Keeping New Construction Dry", ASHRAE Journal, September, 2002, Pages 28-34.

Problems Encountered: Moisture in building materials, particularly in new construction, and not HVAC problems are the cause of mold infestations. There are a variety of causes of moisture in new construction including moisture from the weather (rain or snow) that enters before the building is enclosed, plumbing leaks, wet concrete, or moisture condensing on cold surfaces. All of these can be considered construction-related moisture in new construction, which typical HVAC systems are not designed to handle. The problem is removing the moisture not just from the surface, but from the interior of the material.

Solutions Found: To this end, there are several methods that designers and construction personnel use, with desiccant dehumidifiers being a common tool, as the low dew points that they are able to provide can dry materials inside and out in less time. Additionally, temporary plastic ductwork is sometimes used rather than the building's own HVAC system, thereby reducing the build-up of dust in ductwork, coils, and filters, and targeting the material that is in need of drying. In any case, these suppliers of dry air need to be moved on a daily basis to ensure that all materials are dried quickly and thoroughly, often monitoring moisture content, as "simply supplying super-dry air…does not ensure moisture leaves all materials quickly and equally." Once a part of the building under construction is dry, it is important to keep humid outdoor air out of these areas, and also keep it out of areas being dried. Often this means constructing a temporary enclosure to retain the dry air in the areas in which it is needed.

When drying concrete, it is a more difficult task, as the curing time for concrete can vary, but takes a long time. In order to avoid moisture problems in flooring, there are several options: apply flooring and hope that mold won't grow (voids warranties), wait for drying to occur through natural convection (expensive to wait), seal up the surface (expensive), or use dehumidifiers (effective, less costly). Dehumidifiers can not only dry materials in a shorter period of time, but also dry more predictably and evenly, and can meet specifications required for items such as wood flooring installation. With wall construction, dehumidifiers can dry wallboard joints in a fraction of the time, saving time and money, but also reduces the risk of hidden mold occurring after completion of the building. Dehumidifiers in the installation of wallboards can also be a preventive measure, with joints that do not cure quickly leading to detection of hidden moisture sources.

The HVAC designer can take several measures in order to reduce the risk of a system contributing to mold growth, including specifying tightly sealed ductwork with mastic, not allowing open plenum returns above dropped ceilings, keeping the building slightly positively pressurized, and not operating the HVAC system during construction. Other members of the construction team (architect, general contractor, and owner) can also take steps to reduce the risk of mold including: gypsum board be specified to be installed with a fire sealant bead between floor and bottom edge of gypsum, specify the

moisture content be measured and documented for concrete block walls, gypsum board, and concrete floor slab, have the general contractor control humidity to appropriate standards if installation of wood (e.g. flooring, cabinetwork).

It is a multidisciplinary team responsibility to keep materials dry during construction, and dry them out if they do become wet. By keeping the materials dry, and using the described drying techniques, mold formation can be reduced or elimitated.

Major Grouping: Building Assemblies
Subgrouping: HVAC

R6) Lstiburek, Joseph "Residential Ventilation and Latent Loads", ASHRAE Journal, April, 2002, Pages 18-21.

This article approaches moisture in buildings from the ventilation aspect, stating that in hot humid climates, most houses are over-ventilated, with the uncontrolled airflow (from wind, stack and pressure effects) larger than the designed controlled ventilation.

Problems Encountered: Pressure differences, caused by wind and stack effects, drive air changes and with newer construction, leaky ductwork and unbalanced airflows cause higher air change rates. Since newer construction tends to have reduced building envelope leakage areas due to draft stopping, HVAC systems are operating more often due to these induced increases in air change rates.

Solutions Found: In order to solve the problems of uncontrolled airflow due to HVAC systems, ductwork needs to be tight, air-handlers must be properly sealed, and the airflow must be balanced between rooms. If this is not done, air is induced into the interstitial spaces, causing moisture problems in building cavities. Already many federal, state, and utility construction programs have specifications that require a leakage value of 5%.

Additionally, latent loads in the shoulder months (part-load conditions) are becoming more of an issue; as high performance windows reduce the operation of HVAC systems, as does the oversizing of HVAC systems. This leads to the requirement of dehumidification to reduce the amount of moisture entering from outside through the HVAC system. There are several approaches presented, including stand-alone dehumidifiers, which is low cost but adds heat by operation and has a high operating cost, enhancing air-conditioning systems, which is relatively easy to install but costly, and finally ventilation dehumidifiers which have the lowest operating cost but currently are expensive.

The four measures presented by the author to provide controlled ventilation in hot humid climates without creating latent load problems are: install tight ductwork and air-handlers, balance interior airflows, size equipment correctly, and provide supplemental dehumidification.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R7) Bonnin, Julie "Has Mold Met Its Match?", Mold Reporter, October, 2002, Volume2, Number 6.

The author presents problems in general with mold issues, from the building materials to the education of designers and builders.

Problems Encountered: Research has been done for years, but information has not been readily available or presented from the researchers to the "guys in pickups doing the work". Building materials in use throughout the country are great for mold growth, and include paper-covered gypsum, cellulose ceiling tile, particle board, combined with materials that make it harder for walls to dry out, including fiberglass and cellulose cavity insulation, polyethylene vapor retarders and vinyl wallpaper. By installing tight windows and energy efficient aspects of design, there is no way for the cavities to then dry out if they do get wet.

As houses have become more tightly constructed, moisture in walls has become more of an issue since buildings can no longer dry very quickly. Also, there is a certain amount of predisposition to cold climate construction in building codes throughout the country. An example is vapor barriers, which were designed to keep moisture out of walls in the North, but do exactly the opposite in walls in southern climates. Houses have also become larger and more complex, with lots of complicated details, which make it more difficult to do a decent, well sealed job.

Solutions Found: In Texas, education has been incorporated as a means to help mitigate moisture problems in buildings. This includes videos and pamphlets for owners, designers, and construction workers. They try to convey the idea of a building as a multi-disciplinary effort, with many systems that need to work together, rather than being done piecemeal. The reduced warranty claims make it worth the builders time to build these better homes.

Major Grouping: Building Assemblies
Subgrouping: Walls

R8) Lstiburek, Joseph "Moisture Control for Buildings", ASHRAE Journal, February, 2002, Pages 36-41.

The author presents the environmental loads that cause moisture, particularly in wall construction, and then ways to control moisture, both in general, and then for specific climates.

Problems Encountered: It is the interaction of the HVAC system with the building assemblies and climatic conditions, including temperature, humidity, rain and the interior conditions that tend to be ignored. When not incorporated as part of the design process, these conditions can lead to mold, rot, decay, and corrosion.

There needs to be a balance of moisture that enters and leaves a building construction in order to prevent the accumulation of moisture. The capacity of building materials to store moisture depends on the material properties, time, and temperature. In homes that are primarily constructed of wood, their capacity to store moisture is relatively large, so most water leaks are not a significant problem due to this capacity. In steel framed housed, there is very little storage capacity, so small leaks can lead to moisture problems, whereas masonry construction has good moisture storage capacity. In order to avoid moisture problems in general, the drying time (dwell time) should be short, however, the more thermal insulation in a building assembly, the longer the dwell time.

Solutions Found: Moisture can be controlled by restricting its entry, limiting its accumulation, and removing it. Even though liquid flow and capillary suction are main wetting mechanisms, air transport and vapor diffusion also contribute to the wetting of building assemblies, the magnitude is determined by climate and interior conditions. Though all building assemblies need some sort of protection from vapor diffusion and air transport, in general, it is the climate and season that determine the location vapor and air barriers, pressurization of the building, and additional components for HVAC systems. In cold climates, air and vapor barriers are installed toward the warm surfaces of the interior, which should be kept at low moisture levels. In hot climates, these same barriers should be installed towards the exterior of building assemblies to protect them from getting wet from the exterior, combined with the use of permeable interior wall finishes. In mixed climates, an approach that allows air to flow through the building assembly, using permeable building materials, and installing the vapor barrier in the thermal middle of the building assembly helps to keep the building assemblies from getting wet. The article further presents requirements for building assemblies based on climate-type.

The article also presents several types of materials that restrict the flow of water vapor, and the difference between air and vapor barriers. There are several classes of materials that are impermeable to vapor, rated based on the 'perm' and include vapor impermeable, semi-vapor impermeable, and vapor permeable. Air barriers have the ability to resist both airflow and air pressure, and define the pressure boundary of the building envelope.

Major Grouping: Building Assemblies
Subgrouping: HVAC

R9) Murphy, John "Dehumidification Performance of HVAC Systems", ASHRAE Journal, March, 2002, Pages 23-28.

This article discusses the performance of several HVAC systems and how they do or do not control humidity, particularly for non-residential buildings.

Problems Encountered: Constant volume systems indirectly control space humidity through the use of a dry-bulb temperature thermostat. In constant volume systems, only the temperature of the supply air is varied. Peak dew point conditions are often used to analyze the part-load performance of the dehumidification component of an HVAC system, though this may not represent the worst-case condition for humidity control of the space. Both the outdoor air quantity and the climate impact the capacity of the dehumidifier and indoor humidity conditions. Reducing ventilation rates tends to lower the humidity in the space, but does not solve a high humidity problem related with constant volume systems that are controlled by dry-bulb temperature. In humid climates, increasing the ventilation rate increases the cooling load and the needed capacity for dehumidification. Part-load conditions are often ignored, and can lead to high indoor humidity levels in all climates.

Solutions Found: There are several ways to improve the dehumidification performance of constant volume systems presented by the author, including tempering supply air (over cool air to remove moisture, then reheat), treat the outdoor and return airstreams separately, adjust the fanspeed, and using face-and-bypass dampers (allows some of the air to bypass the cooling coil).

In variable air volume systems, they usually provide effective coincidental dehumidification for a variety of interior conditions. Variable air volume systems adjust the amount of air supplied, but keep the supply air temperature the same, so all spaces receive dry air. These systems also use the supply-air tempering, reheating air that has been cooled in order to take additional moisture out. Again, there are ways to improve the performance of these types of systems including treating the outdoor air separately, and lowering the supply air temperature.

In the past, dry-bulb temperature has been the main controller of indoor space conditions, not taking into account the humidity levels specifically. Constant volume systems tend to be problematic in part-load conditions, while variable air volume systems perform better under a wide condition of load types. Both the full and part-load conditions should be considered when an HVAC system is designed and selected.

Major Grouping: Building Assemblies
Subgrouping: HVAC

R10) Khattar, Mukesh K. Michael J. Brandemuehl "Separating the V in HVAC: A Dual-Path Approach", ASHRAE Journal, May, 2002, Pages 37-42.

In order to address indoor air quality issues, three categories of solutions are presented by the authors; dilution of pollutants via ventilation, removal of pollutants with filters, and destruction of pollutants, with the focus on dilution as the most popular method.

Problems Encountered: There are two main functions that the air supplied to the space does; provide thermal conditioning and dilute indoor air with outside air for indoor air quality. While constant volume and variable air volume systems operate similarly at design load conditions, both providing the same amount of air, at part load conditions, the constant volume system adjusts the supply air temperature, while the variable air volume system adjusts the amount of air supplied to the space. With the reduction of air being supplied to the space, there is a potential for unacceptable indoor air quality.

Solutions Found: Dual-path systems offer the ability to provide adequate ventilation, while addressing the humidity issues. With single-path systems, when the compressor is in the off cycle, the air behaves as infiltration (thermally), as the ventilation air is not conditioned. Additionally, when the compressor cycles, while it is in the off cycle, air continues to blow over the coils, allowing moisture to collect, and then re-evaporate into the space, with cycling time of the compressors having a large impact on the indoor humidity levels.

Dual-path systems in when the ventilation air and return air streams are conditioned separately. There is a higher initial cost, and the controls must be integrated on at least two of the following synergies; excellent humidity control, avoiding simultaneous heating and cooling, having a single air distribution system, and finally configuring and packaging the HVAC system to reduce cost. By conditioning the ventilation and return air separately, improved air quality with desired temperature and humidity controls under all part-load conditions can be achieved. This requires improved and advanced components that can operate effectively over part-load conditions.

Major Grouping: Building Assemblies
Subgrouping: Mold

R11) Armstrong, Sarah, Jane Liaw "The Fundamentals of Fungi", ASHRAE Journal, November, 2002, Pages 18-22.

This article primarily deals with the issues surrounding fungi (including molds) and particularly their health aspects and factors that cause them to grow. Not particularly building related.

Problems Encountered/Solutions Found: It concludes that "one may wish simply to prevent mold from growing in buildings by acting quickly when water leaks, spills, or floods occur indoors, being alert to condensation, and filtering air."

Major Grouping: Building Assemblies
Subgrouping: HVAC

R12) Harriman III, Lewis G. “Dehumidification Equipment Advances”, ASHRAE Journal, August, 2002, Pages 22-27.

This article describes and compares three dehumidification technologies currently available for humidity control in buildings. Some of the main issues are ineffective dehumidification, and the location of the dehumidifiers.

Problems Encountered: These technologies have come about due to humidity problems that occur during off-peak hours, when humid ventilation air can flow through inactive coils, keeping moisture loads high. Often times short run times of equipment that has been sized for peak loads, and is controlled only by a dry-bulb thermostat, is not effective in controlling excessive moisture in occupied spaces. Adding capacity does not alleviate this problem, but exacerbates it as it increases the amount of time that the equipment is operated with short cycling times, and undersizing equipment is a slightly better strategy. Dehumidifiers are often placed on the incoming air, since that is where much of the moisture is.

Solutions Found: Ventilation air dehumidifiers have been in development and are designed to handle 100% outdoor air. By changing the location of the dehumidifier so that it dries the ventilation air, continuously dehumidifying the largest and most constant moisture load, the indoor humidity levels are reduced. Mechanical dehumidifiers with passive dessicant wheels cannot operate without exhaust air, but the dessicant wheel absorbs moisture and heat from the incoming air, thereby reducing the dehumidifier load. Mechanical dehumidifiers with sensible heat exchangers avoid the need for exhaust air, using an air-to-air heat exchanger to pre-cool and reheat the outdoor air after it has been dried with a mechanical dehumidifier. Finally, the two-stage dessicant/mechanical dehumidifier uses condenser heat from the mechanical dehumidifier to reactivate the dessicant wheel. This has the ability to dry the air “more deeply”.

Several questions to ask in selecting a ventilation dehumidifier include the initial cost, the peak dew-point performance, part-load performance, and energy usage, particularly at part-load conditions. Since ventilation air is the largest part of a building’s total moisture load, serious consideration should be given to dehumidification. Part-load analysis is an important aspect to analyze, as most operation occurs under part-load conditions, and not peak design conditions.

Major Grouping: Building Assemblies
Subgrouping: Crawlspace

R13) DeWitt, Craig "Crawlspace Myths", ASHRAE Journal, November, 2002, Pages 20-24.

This article dispels the myths behind the ventilation of crawlspaces throughout the United States. It gives some historical reasoning as to why crawlspaces were originally ventilated, and why that is not necessary today.

Problems Encountered: Though crawlspaces are found predominantly in South Carolina, but are common across the center of the United States, historically the solution to moisture problems in these spaces was to provide or increase ventilation. Moisture in crawlspaces leads to mold and decay, condensation on ductwork and mold on joists. We now use air conditioning much more, causing much cooler temperatures indoors, leading to more condensation problems, which were not the case when initial building codes and ventilation guidelines were created. Excess moisture in crawlspaces can cause the following problems: high relative humidity, leading to mold growth, high dew-point resulting in condensation, leading to mold growth, and increased latent loads.

Solutions Found: ASHRAE removed crawlspace ventilation guidelines beginning in 1997 due to changes in buildings; the National Association of Home Builders now recommends that vents be closed in the summer as a means to prevent mold. By warming the surfaces, by adding insulation or lowering dew-point temperature, condensation issues can be reduced. Venting the crawlspace can keep it dry only when the mixture of ventilation air and crawlspace air results in a relative humidity level below 90% at every surface in the crawlspace. From an energy standpoint it does not make sense to vent a crawlspace in any climate.

The crawlspace should either be made part of the inside, and building envelope get pushed outward to include the crawlspace, or make part of the outside and have the floor system above the space be fully insulated with moisture and air barriers. Exterior water has to be directed away from the foundation, and crawlspace soil should be covered with a vapor retarder. Capillary breaks should be used to restrict capillary moisture movement. Some more complex homes may require a dehumidifier in the crawlspace to control humidity levels.

Major Grouping: Building Assemblies
Subgrouping: HVAC

R14) Ask, Andrew C. "Ventilation and Air Leakage", ASHRAE Journal, November, 2003, Pages 28-34.

This article discusses the problems with buildings that leak and how to measure the amount of leakage to appropriately size HVAC systems. It is normal for buildings to leak air and water, but designers should have the goals of quantifying leakage, reducing leakage, and control leakage through building pressure and HVAC systems.

Problems Encountered: By not properly or adequately quantifying the building's air leakage, the building's pressurization can be inappropriate, leading to moisture problems. If hot humid air enters through the building envelope, it can cool below its dew point and create condensation within the building construction. This damages building materials and promotes the growth of mold.

Solutions Found: Understanding and measuring the building's air leakage can lead to better design of the HVAC system and its components. Several types of methods exist to measure and express a building's air leakage, including 'crackage' method, calculating the air exchange rate, pressure differentials, one equivalent size hole, and blower door tests. The 'crackage' method is a rough estimate, determined by the width of cracks around openings. The air exchange rate is somewhat better, taking the volume of the building and divide by 60 to get cubic feet per minute.

By tightening the building envelope, through sealing off the soffit overhang area in the example provided in the article. A blower door test was then conducted, the data from which provided information the HVAC designers could then use to adequately design pretreatment system for the incoming air based on data rather than approximations. The outside air supplied should not exactly equal the exhaust, as this does not account for the leakage that occurs in all buildings.

Major Grouping: Building Assemblies
Subgrouping: Walls

R15) Best, Al, Frank Clark, et al. “Water Intrusion and Remediation for Wood Frame Homes with EIFS”, EIFS Review Committee, January, 1999.

This article addresses issues and problems with Exterior Insulation and Finish Systems (EIFS) and how to avoid moisture problems with this type of wall system.

Problems Encountered: When moisture enters non-drainable (barrier) EIFS, degradation of the underlying materials can occur. Since there is no drainage cavity, they do not necessarily have a weather-resistive barrier behind them, and they have limited ability to dry, these wall systems are prone to mold growth. EIFS also have a face sealed barrier type of construction that resists water penetration at the outer surface, but still does not drain the moisture that gets behind. The interfaces between the EIFS and other materials used are common sources of water intrusion, with the most frequent source of moisture being the windows, however other building penetrations such as doors, and vents, as well as flashing and construction details also can allow water to enter.

Solutions Found: Early detection of water intrusion as well as testing these water prone constructions can help to minimize or prevent water damage. Testing for elevated moisture levels is recommended on an annual basis in this type of wall construction. In order to eliminate water intrusion, the following measures should be taken: install effective kick-out flashing at roof to wall intersections, effective caulk joints should be installed, install effective flashing for decks and cap flashing for chimneys. The design, weather (particularly rainfall), exposure and performance of other building components will help to determine the water tightness of the EIFS construction. The local climate conditions do influence the degree to which the problem can exist.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R16) NAHB Research Center "Mold in Residential Buildings", Toolbase Technotes, July, 2001.

This article addresses issues and practices that homeowners and builders should be aware of regarding mold in residential buildings.

Problems Encountered: There are several typical sources for moisture that increase the relative humidity of indoor air, including people, bathing, cooking, plants, washing and drying of dishes and clothes, humidifiers and outdoor ventilation. Additionally moisture can come from water leaks from pipes, and rain leakage through windows, roof flashing and ice dams. Common building materials such as wet cellulose materials (paper and paper products, cardboard, ceiling tiles, wood and wood products) are conducive for mold growth.

Solutions Found: The first step is to eliminate excessive moisture in order to stop mold growth. Early detection and quick clean up of excessive moisture problems reduces the amount of damage. Controlling indoor air moisture can limit the probability of mold growth occurring due to condensation on interior surfaces such as walls, windows, and areas near air conditioning supply registers. By increasing the surface temperature (though insulation or increase circulation of heated air) or reducing the moisture levels in the air (through increased ventilation and repairing air leaks) moisture from condensation can be reduced or eliminated. Proper drainage for both roof rainwater and ground grading will assist in reducing the possibility for moisture intrusion.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R17) Carroll, Robert. "Are You Awash in Water Problems?", Building Analysts, Techlink.

This article addresses issues and problems of moisture and water intrusion in California homes.

Problems Encountered: Damage from water intrusion often goes unnoticed since it is normally contained within the wall construction, leading to possible structural damage in wood studs and joists. Defective building materials and substandard construction practices are related to reasons that water enters buildings. Defective window frames due to improper installation of sealant or flashing materials, as well as improperly installed or even missing flashing at the edges of roof can cause water intrusion. As stucco is one of the most common exterior finishes used on homes throughout California, the problem of water penetrating the exterior wall finish materials is a serious problem. Stucco is brittle, and has little flexibility, so it can suffer cracks, through which water can enter. Also improperly installed weather barriers or improper termination of stucco weather barriers at openings can also lead to moisture problems. With EIFS, the outer surface is designed to resist water, but has no way of getting rid of moisture that gets behind the outer surface. Incomplete application, failure of outer finish openings, or poorly detailed joints can cause the delamination of gypsum board, and the growth of mold.

Solutions Found: Code-approved stucco is not necessarily a problem, as occasional hairline cracks are common. Careful observation and timely repairs can help with remediation issues. Water intrusion should be prevented completely, and detection of potential moisture problems should occur as early as possible.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R18) DeKorne, Clayton. "Mold Prevention", e-build, originally from Custom Home Magazine, April, 2002.

This article addresses moisture problems, and offers moisture control and sound building practices as the "best defense".

Problems Encountered: Houses are built tighter today, and the poly vapor retarders and vinyl wall papers used these days traps moisture that is able to infiltrate a wall, and does not allow for the water to dry out. Modern building materials are also "more mold-friendly", with mold metabolizing adhesives used in wood products more easily than the cellulose in solid wood. Basically in the houses today that are wetter, mold has more to feed on.

Solutions Found: Moisture must e controlled, as mold grows in environments where the relative humidity exceeds 70%, however this only becomes an issue if the moisture condenses out of the air. Proper flashing and other water-shedding details on building components (walls, roofs, windows, doors) and proper drainage around foundations, and proper detailing of the thermal envelope to prevent moisture condensing on interior surfaces can reduce and prevent moisture problems. Wide overhangs shield walls from rain, roofing felt should be extended well over the top of base flashing, proper insulation of problem areas (exterior corners, junctions of roof and wall framing, and rim joists), proper flashing installed beneath the trim and housewrap, and the insulation of cold water pipes and sealing HVAC ducts are solutions to moisture problems in buildings. Exterior walls (particularly for stucco and brick) should have continuous drainage planes between siding and sheathing, use rain screens for wood siding, and have proper foundation drainage.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R19) Stock Building Supply. "Smart Moisture Management", Online Training Academy, Building Media Inc, 2003.

This article addresses the keys to reducing mold, moisture and mildew in building construction.

Problems Encountered: Often moisture problems are caused by improper design or inadequate maintenance, particularly in older homes, though newer construction has gotten more attention for large-scale moisture problems. By trying to energy efficiency, homes became more airtight that were not able to breathe like older 'leakier' homes. Also, more complex home designs created an increased potential for moisture intrusion. Moisture comes from water leaking into the building envelope and from excess humidity indoors. Causes include inadequate or improperly installed flashing, poor roof design (shallow overhangs, unprotected gable ends), inadequate grading, and incorrect or poor installation.

Solutions Found: With proper design and construction, a home can be both energy efficient and free of moisture related problems. Some considerations for homes include using roof overhangs and other features to avoid bulk water intrusion, correct use of flashing to divert water away from openings, installation of insulation without gaps or voids, use of a continuous weather resistive barrier on exterior walls, cover crawlspaces, and use of exhaust fans to expel moisture from inside.

Major Grouping: Building Assemblies
Subgrouping: HVAC

R20) Lstiburek, Joseph. "Moisture, Building Enclosures, and Mold; Part 1", HPAC Engineering, December, 2001.

This article addresses the issues of how water gets into a structure, how it is unable to leave, and the ensuing HVAC issues.

Problems Encountered: Buildings leak and moisture gets into wall cavities because conditioned air escapes and outside air enters. The problem is that many of the materials used today do not allow these building constructions to dry out. The construction team often performs and acts as "a big dysfunctional family." Also, many methods use prevent wetting, but then also prevent drying, and many materials used today absorb moisture, and then are difficult to dry out.

Solutions Found: A whole-building approach must be used. Control water problems, control airflow across building enclosure, control the air pressure across the building enclosure, and ventilate and condition the building enclosure in a controlled manner for humidity. Managing rain and ground water through proper drainage, making sure that walls have drainage planes (including drainable EIFS), not using vinyl wall covering or paper-faced gypsum, and use "smart" vapor barriers including kraft facing fiberglass batt.

Major Grouping: Building Assemblies
Subgrouping: HVAC

R21) Lstiburek, Joseph. "Moisture, Building Enclosures, and Mold; Part 2", HPAC Engineering, January, 2002.

This article addresses the issues of how water gets into a structure, how it is unable to leave, and the ensuing HVAC issues.

Problems Encountered: Cantilevers and complicated house designs, turning dropped ceilings into return-air plenums and lots of penetrations through the walls with additional leaks lead to many moisture problems in housing. The penetrations are often not sealed properly, and fiberglass insulation that is commonly used does not work to stop airflow. Air barriers are often forgotten or poorly constructed, and buildings are depressurized through the use of bathroom and kitchen exhausts.

Solutions Found: Engineers need to control the air, not allowing holes, control the pressurization, keeping the buildings positively pressurized, create a tight building, and control humidity. Air tightness should be specified, even requiring that an envelope be commissioned, buildings should be pressurized between 2 and 5 pascals, and optimally the ventilation and humidity would be controlled by separate but integrated systems.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R22) APA-Engineered Wood Association ": Controlling Mold and Mildew", Build A Better Home, 2003.

This article addresses the issues of how to prevent moisture problems through proper design, construction and maintenance of buildings.

Problems Encountered: This article grants that moisture problems are caused by high relative humidity, particularly in current wood products. Prolonged moisture can lead to structural damage. Moisture trapped in wall cavities can also lead to mold growth, including water through window, door and other wall penetration.

Solutions Found: Moisture needs to be controlled through use of exterior management systems (such as flashing), correct storage of materials, and maintenance and operation of the building (including controlling interior moisture levels). In basements, providing proper drainage, proper ventilation, using a dehumidifier, and installing proper exhaust vents can assist with reducing the potential for moisture problems in this space type. By using overhangs, installing proper flashing, and designing wall to prevent condensation from occurring within wall cavities problems due to moisture can be virtually eliminated. Installing light switches that activate exhaust vents, and discharging air from clothes driers to the outside can address solutions to moisture problems caused by people.

Major Grouping: Building Assemblies
Subgrouping: Walls

R23) e-build "New Interior Panels Provide Outstanding Resistance to Abuse, Water, Mold and Fire", Business Wire, October, 2003.

This article presents a new material that resists mold formation through its construction and materials.

Problems Encountered: Typical panels rely on facing material for strength and as a primary water barrier, however if the facing is torn or pierced, delamination can occur, causing the products to lose their strength and their water resistance.

Solutions Found: These new panels are designed to resist water through the core, and have the ability to be installed and finished like traditional wallboard. They have a uniform composition and do not have a face layer to separate from the core, and resist moisture.

Major Grouping: Building Assemblies
Subgrouping: Windows

R24) Jackson, Ric "Mold: Window Manufacturers Beware: It's the Next Asbestos of the Litigation World", Door and Window Maker Magazine, October, 2002.

This article presents problems related to windows and moisture in buildings.

Problems Encountered: Mishandling of windows in delivery, improper installation, and poor maintenance of windows leads to moisture and condensation problems in buildings. Also, as tract houses are constructed in 60-90 days, often there is not the appropriate attention to details, including the sealing and trim around windows.

Solutions Found: By controlling the handling of windows, educating the homeowner to maintenance needs, and detailed instructions and monitoring of installations can reduce the potential for problems with windows later on, including moisture and condensation issues. By using better insulating components in windows such as warm edge spacers, gas fills and low-e coatings, the risk of condensation can be significantly reduced.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R25) Morey, Philip R. “Poor Building Design Leads to Fungal Growth”, Aerias.

This article presents problems and causes related to moisture in buildings.

Problems Encountered: Reasons for moisture problems in buildings are due to a variety of issues, including the integrity of the building envelope and the properties of the materials and construction techniques used. Many of the materials used in construction today were not used in constructions 50-70 years ago, and are more prone to mold growth. Materials include paper fiber gypsum board, porous insulation, vinyl wallcovering, pressed wood products, porous ceiling tiles and textile wall and floor coverings. Temperature gradients on surfaces in buildings “have become non-uniform.” Moisture can enter the building through a variety of paths, including leaks, vapor migration and humid outdoor air. If flashing fails, wind driven rain can enter a building envelope, as well as through construction defects.

Solutions Found: The following measures are recommended, particularly for modern air-conditioned buildings in warm humid climates: install vapor and air retarders near exterior surface of envelope, keep building slightly positively pressurized, dry construction materials, use permeable wall coverings, use materials that are not prone to mold growth, and avoid cooling indoor spaces below outdoor dew points.

Major Grouping: Building Assemblies
Subgrouping: Walls

R26) Carll, Charles. “Rainwater Intrusion in Light-Frame Building Walls”, Forest Products Laboratory.

This article presents problems and causes related to moisture in light-frame building walls.

Problems Encountered: Energy efficient construction practices are partially to blame, since well-insulated, air-tight walls do not allow moisture to dry out as quickly as more ‘leakier’ buildings. In snowy climates, inadequate insulation and air infiltration are also the causes of damaging ice dams on roofs. Buildings are often not properly sited, without proper overhangs, and have architectural details that are difficult to construct in a non-leaking manner. Poor detailing, construction and inadequate inspection also contribute to moisture problems. Often some visual sign of damage must occur before moisture issues are addressed. Building codes also often do not have criteria that can be used to evaluate if a detail or design meets code requirements.

Solutions Found: Climate conditions including average annual rainfall and hygro-thermal conditions and typical interior conditions should be carefully classified and designated. Since vapor diffusion and air movement are related to moisture movements with in building constructions, a holistic approach must be taken. There are some factors that determine the resistance of a wall to moisture damage, including resistance to leakage, resistance of materials to damage from wetting, and drying ability of the wall, however these are difficult to quantify. Local knowledge, experience and attention by reputable practitioners help erect buildings that are resistant to moisture intrusion. However there needs to be a means to characterize the rain exposure of a building (including other water sources) and the means to evaluate a building’s leak resistance or moisture tolerance.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R27) Axelrad, Robert, Philip J. Bierbaum editors "The Building Air Quality Action Plan: Appendix C: Moisture, Mold and Mildew", Environmental Protection Agency, June, 1998.

This appendix provides background on the causes of moisture problems and steps to take to reduce these issues, including identifying common problem areas.

Problems Encountered: Water vapor enters a building through accidental spills as well as through openings (planned or unplanned) in a building envelope. Cooler surfaces are often found in wall cavities due to cold wind blowing through cracks in the envelope. Common problem areas include exterior corners, setback thermostats, air conditioned spaces, thermal bridges, windows, and hidden condensation.

Solutions Found: Reducing the vapor pressure, increasing the air movement at the surface or increasing the air temperature can reduce moisture problems. First the dominating factor (surface temperature or vapor pressure) must be determined to assist in selecting a control strategy. For surface temperature dominated mold, the temperature of the air should be increased (via raising the thermostat or improving air circulation) or decrease the heat loss from surfaces (through increased insulation or reduction in cracks), whereas for vapor pressure dominated mold the source of the moisture must be directed to the exterior, the moist indoor air be diluted, or use of dehumidification. The common problems listed above can be mitigated through removal of obstructions to airflow, increase or maintain interior temperatures during heating periods, ensure vapor barriers, sealants and insulation are installed properly, use insulating sheathings, and elevating the temperature of the first condensing surface through the installation of insulating sheathing to the interior of wall framing.

Major Grouping: Building Assemblies
Subgrouping: Slabs

R28) Suprenant. Bruce A. “Moisture Movement Through Concrete Slabs”, Concrete Construction, November, 1997.

This article reviews the problems of moisture in concrete slabs and ways to minimize problems.

Problems Encountered: Problems caused by moisture movement through concrete slabs have increased in the past few years due to “fast-track construction methods and changes in the chemistry of floor-covering adhesives.” As buildings are constructed faster, there will continue to be problems. Also, limitations in floor-covering adhesives due to environmental legislation have made these adhesives need to be more water-sensitive. By using impervious coatings on concrete slabs, often used before the concrete slab is fully dry, caused the slab to retain more moisture, and dry out much more slowly.

Solutions Found: Capillary breaks, gravel can be used, should be implemented to reduce the initial moisture flow from the slab into the occupied space. The most effective method for reducing moisture flow into the occupied space is by using a vapor barrier over the gravel layer, which is on top of compacted clay. Proper treatment of the ground below the slab should be completed to encourage both drying of the concrete and reduction of moisture from the ground and slab into the occupied space.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R29) Andrews, Steve. “Water Management: Drain Everything: Control Moisture Problems, and You Can Control Mold”, Professional Builder, June, 2002.

This article reviews the problems of moisture in building envelopes and provides some recommendations (some from the Water Management Guide by Lstiburek).

Problems Encountered: Bulk water must be managed, in all its forms, by controlling indoor relative humidity, draining water down and away from buildings. Complex wall and roof intersections often lead to difficulties with installing correct and effective drainage planes. Some common problems are that windows leak, and dampproofing does not stop the wetting of walls in basements.

Solutions Found: Using face-sealed barrier approaches can help with reducing moisture in walls, but only if they are perfectly installed and that caulking that will not deteriorate is used. Screen assemblies are often used as a secondary line of defense, particularly for brick veneer or wood sided walls. The proper detailing of windows, including the integration of flashing with a drainage plane can also eliminate water from entering wall cavities. Dampproofing is not needed if proper drainage methods are used, which starts with proper overhangs and gutters, always directing water down and away from the building. Capillary breaks are needed over footings so that water does not make its way into basement walls, which should be vapor permeable to allow moisture to pass through, rather than be trapped, and be taken care of by the mechanical system. Avoid the use of sand as a layer between the poly and the slab, as water tends to pool.

Major Grouping: Building Assemblies
Subgrouping: Crawlspace

R30) Tooley, Jeff. “Building a Sealed Crawlspace”, The Journal of Light Construction, October, 2003.

This article reviews the problems of moisture in crawlspaces and provides some ways to avoid these problems.

Problems Encountered: Vents for crawlspaces do not work. Also, sealing crawlspaces that have no vapor barrier and no conditioned air supply can also cause mold and rot in joists. Building codes, such as the International Residential Code, are not very clear about how exactly to detail an unvented crawlspace.

Solutions Found: The solution begins with vapor barriers that are sealed with mastic, so that they are airtight and watertight. Foam board is fastened to the poly in foundation walls. The thermal boundary and air pressure boundary of the building is located in an appropriate location. A dehumidifier should be used to remove any excess moisture in the crawlspace, as the framing may have absorbed some moisture. At joints, a shingle effect is created to handle the correct flow of water away from the building. Some practitioners install a humidity sensor under the floor, with an alarm in the occupied space to alert homeowners when moisture may be becoming a problem (reaching elevated levels).

Major Grouping: Building Assemblies
Subgrouping: Moisture

R31) Hoeschele, Marc, Rick Chitwood. "New Construction Report Card: In Order to Make Energy-Efficient and Comfortable New Houses, California Builders Need to Pay More Attention to the Details", Energy Auditor and Retrofitter, January-February, 2003.

This article reviews the problems of new home construction and moisture issues resulting from more complicated homes.

Problems Encountered: As houses get more complicated, particularly for California, and the construction team tries to cut costs, there is a lack of attention to problems and details that impacts the overall performance of the end building. Complications in design include cantilevered floors, interior columns, arches, and soffits. Problems include low HVAC flow and inadequate insulation. More complicated home designs lead to additional penetrations for utilities, which, if not properly sealed, can lead to leaky interior wall cavities.

Solutions Found: In general, less attention can be placed "on the insulation installation details and proper application of barriers than other parts of the country." Simple, flat ceilings are more conductive to proper air sealing and stopping draft than more complicated ceiling and architectural details. More attention to details needs to be taken with more complicated designs, requiring more accurate and specified design aspects. Also, the climate needs to play a role in orientation and design of the buildings. Details such as arches, turrets, and soffits need to be given thought as to how they will be draftstopped and insulated. The construction team needs to work together to improve overall house performance, rather than taking a piecemeal approach, so that the thermal, pressure and moisture barriers are installed in a continuous manner. By improving training protocols and tools, having tighter builder specifications and increased compensation for high-quality work (so that quality is emphasized rather than speed) and having measurement and verification of the building, the performance and comfort can be improved for new homes in California.

Major Grouping: Building Assemblies
Subgrouping: Walls

R32) Altenhofen, David. “To the Rescue: Designing Exterior Walls to Control Mold”, Buildings, November, 2002.

This article reviews the problems designing exterior walls to control moisture and mold, with a focus on air barriers. Movement of air into and out of the building can be controlled by an air barrier, which should be a continuous system in the wall construction. This air barrier can be made of a variety of materials, including exterior gypsum sheathing, sealant, and sheet metal flashing, and should be able to withstand loads from differential pressure, building movement, and must form an envelope around the building from foundation to roof.

Problems Encountered: The combination of leaks and condensation lead to mold growth in exterior walls in particular. Walls whose performance is based on a perfect weather barrier, and try to seal every surface, joint, and penetration often fail, as this perfect weather barrier scenario is unrealistic. Of particular concern is the installation of air barriers across penetrations (doors, windows) and at the joints (floor, roof).

Solutions Found: The determination of the air barrier being vapor permeable of a vapor retarder is due to the location of the air barrier within a wall assembly. The air barrier is typically an applied membrane when building insulation is located in the air cavity, but it should be waterproof, and drained to the exterior in all cases. By using an applied membrane, covering the entire surface, tying into the foundation and the roof, a reliable wall system is created that minimizes water intrusion, controls condensation, and separates the indoors from moist materials. Using the rainscreen and air barrier approach, “with inherent safety and redundancy, provides higher-quality wall systems”.

Major Grouping: Building Assemblies
Subgrouping: Attics

R33) Hardy Environmental Services. “Mold Remediation-Information”, Hardy Environmental Services-Solutions, 2003.

This article reviews the problems of mold in attics, basements and crawlspaces, however does not really offer any solutions, as they are remediators, and look to remove and clean up mold and moisture problems.

Problems Encountered: One of the major contributing factors to mold in attics is inadequate ventilation, including bathroom vents that are discharged to the attic. This traps moist, warm air and leads to the formation of condensation on sheathing and framing. In basements, cool temperatures and high humidity leaking through cracks in mortar or concrete block walls can lead to problems. Crawlspaces have historically been ideal places for mold to grow-dark, cool, and moist, particularly in coastal areas. In wall cavities, mold often happens in exterior walls dues to leaky windows, air infiltration, and plumbing leaks.

Solutions Found: Improving attic ventilation, testing for moisture in areas prone to moisture, or where moisture is thought to be a problem, and the installation of dehumidification equipment where necessary-particularly in crawlspaces. Protectants, including the use of mod-inhibiting paint, are often used after a mold problem has been discovered and cleaned up.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R34) Bas, Ed. “Mold is a Major IAQ Concern for Home, Building Owners, Tenants”, Snips, January, 2002.

This article reviews the problems of new home construction and moisture issues resulting from tighter, warmer/cooler buildings and problems with HVAC equipment. Also included are factory built homes.

Problems Encountered: Buildings built after the 1970s were built tighter, controlled to be warmer in the winter and cooler in the summer, with more furnishings. Additional insulation and tighter doors and windows lead to reduced air infiltration, which can lead to a buildup of humidity which has no means of drying out. Cooling systems are typically oversized, leading to shorter cycling of these systems, thereby not allowing enough humidity to be taken out of the air. With factory built homes, tears and rips in the belly board are often found, so that combined with the use of vinyl, plastic and other non-porous wall and floor coverings allows water to condense. Lack of building maintenance, poor air filtration and improper operation of systems each can lead to moisture problems in buildings.

Solutions Found: Proper sealing of HVAC ductwork, not oversizing equipment, and allowing for additional dehumidification can reduce the potential for moisture damage. Careful and proper handling and installation of building components will also help to reduce moisture problems in buildings.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R35) Michigan State University Extension. “Moisture Problems in the Home”, Home Maintenance and Repair, E-2109, December, 1998.

This article reviews the problems of moisture in homes in general, with some focus on homes in Michigan.

Problems Encountered: The addition of more insulation has resulted in homes that not only trap heat, but also trap moisture. Cooler surfaces lead to condensation problems, both with lower indoor temperatures due to air conditioning, and leakier homes with poorly weatherized and insulated walls, windows, pipes, and concrete surfaces. High indoor humidity levels also lead to moisture problems.

Solutions Found: Solutions include the obvious reduction of indoor humidity levels through ventilation, warmer temperatures, or dehumidification, covering the crawlspace with a vapor retarder, providing adequate natural ventilation in attic and crawl spaces, and using exhaust fans to air a newly constructed house. Repair or replace appliances or unvented heating units, add insulation to cooler exterior wall surfaces, and add caulking or weatherstripping. Vapor retarders should be used with batt insulation in basements.

Indicators of Moisture: “sweating” on windows, peeling exterior paint, discolored interior walls, and warped wood siding are all indicators that there may be moisture problems in a building.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R36) Canada Wood Council. “Moisture Control Measures”, Air and Vapor Barriers, 2002.

This article reviews the problems moisture for a variety of building components and the potential solution to them.

Problems Encountered: Windows can leak around their perimeter or can be a cool surface via conduction through the window frame. Framing intersections can lead to additional problems with thermal bridges, discontinuous air barriers and inadequate insulation. Attics and ceilings can have problems due to air leakage and diffusion of warm indoor air into these spaces. Flat roofs rely on wind pressures for ventilation and are often only vented at the perimeter which makes them vulnerable to condensation, as are mansard roofs, as little moisture is allowed to escape from the roof due to the steeply sloped sides.

Solutions Found: Moisture levels in buildings can be controlled by: limiting the sources of humidity indoors, using air barriers, using vapor barriers, and ventilating excess moisture. Improving the thermal efficiency of windows, providing adequate insulation and air barriers (including continuous air barriers at ceilings) and continuous vents at eaves and ridges to provide air movement needed to reduce the risk of moisture.

Major Grouping: Building Assemblies
Subgrouping: Walls

R37) Adams, Phyllis F. “Condensation Problems in Walls”, Penn State Cooperative Extension, D-9, 1995.

This article reviews the problems condensation in walls, including the symptoms, causes, and what to do to solve them.

There are several symptoms of moisture problems in walls; the blistering and peeling of exterior paint, damp insulation in walls, formation of ice in walls, and water gathering on floors or carpet and finally the visibility of mold.

Problems Encountered: Water vapor is a particular problem in walls, as it moves through the assembly and condenses on cold surfaces. If there is not a properly place vapor retarder, insulated walls will hold the moisture within like a sponge. This leads to a reduction in the effectiveness of insulation and eventually the deterioration of wood structural components. Moisture problems occur when insulation settles, leaving a cold spot.

Solutions Found: Recommendations to reduce moisture problems in the home include proper sealing, reduction of air leaks, and prevent moisture from entering the walls. Attention should be paid to exterior corners and walls to be properly insulated, as well as have a vapor retarder on the interior warm surface. In new houses, vapor retarder with permeability rating of 0.1 or less should be used, whereas with existing homes, two coats of oil based paint or paints with a low perm rating should be used to reduce vapor transmission.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R38) Brook, D.M. “Home Moisture Problems”, Oregon State University Extension Center, EC 1437, February, 1995.

This article reviews the moisture problems in homes, the causes, symptoms, sources, and solutions used.

It is important to look for moisture sources, determine how to correct or control them, minimize the humidity levels indoors, and provide ventilation where it is needed. Depending on the building air-exchange rate, “the same amount of moisture may cause no damage in one house, while resulting in mold” in another. Excess moisture symptoms identified include odors, frost on cold surfaces, discoloration and staining on surfaces, deformed wood surfaces, peeling paint and crusty, powdery concrete and masonry.

Problems Encountered: Low humidity indoors may reduce the chance of moisture problems in localized areas, but not necessarily throughout the house. Moisture can come from problems with foundation drainage, lack of moisture barrier beneath slabs, siding installed within 12 inches of the ground, inadequate drip edges and flat ledges from outside moisture. On the inside of buildings, moisture can come from occupants and domestic activities (baths, showers), mal-functioning or unvented combustion appliances, storing firewood indoors, attic bypasses, damp construction material and plumbing leaks.

Solutions Found: It is important to look for the sources of moisture and the means for moisture from outdoors to enter into the building. Sealing attic bypasses such as plumbing chases, spaces around chimneys, and around light fixtures can reduce the potential for moisture problems. When constructing houses, exhaust fans should be used to dry out materials used. Window condensation can be reduced by installing storm windows, and ventilation should be used to reduce humidity levels and increase air exchange rates. Building cavity ventilation is important for crawlspaces, attics, and other unconditioned spaces, spot ventilation should be used in areas of higher humidity (bathrooms, kitchens) and whole-house ventilation if needed to control the amount of fresh air and humidity. Attics, floors and walls should be appropriately insulated, drainage problems should be fixed, and dehumidification devices used as necessary.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R39) Adams, Phyllis F. “An Overview of: Moisture Problems in the Home”, Penn State Cooperative Extension, D-8, 1995.

This article provides a basic overview of moisture problems in homes, including problem areas and causes of moisture issues. However, it does not offer any solutions.

Problems Encountered: The main problem areas in homes for moisture are windows, walls, ceilings, basements, attics and crawlspaces. Frost or fogging occurs on windows, stains or discoloration occurs on walls and ceilings, exterior siding peels or blisters, cold spots appear on walls due to moisture in insulation, plywood materials delaminate, and ice and frost appear on the underside of roof boards.

The causes of these problems includes inadequate ventilation in spaces (home, attic, crawlspace), high indoor humidity levels, lack of or improperly installed vapor retarders or insulation, air leaks or water infiltration from outdoor sources.

Solutions Found: Identifying the causes and symptoms is a first step in solving moisture problems.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R40) Brautigam, Jack. “Reducing Moisture Problems”, HealthyGoods, 2003.

The author presents sources and consequences of moisture entering building assemblies, and some suggestions as to how to correct or control the moisture movement.

Problems Encountered: Moisture problems can cause staining on surfaces, blister paint, fog up windows and reduce the effectiveness of insulation. Water can enter the home through leaks in the roof, walls, windows, or foundation. Poorly maintained roofs, gutters and downspouts can also lead to water damage. Adequate ventilation has become more of an issue as new homes tend to be more tightly constructed. Soil moisture can lead to problems in crawlspaces, while cracks or penetrations in the floor can lead to moisture entering the occupied living space. Humid air from the crawlspace can also be pulled into the ductwork if ducts are located in the crawlspace.

Solutions Found: Using a damper in the exhaust duct that closes when exhaust fans are not on can prevent air from escaping, reducing the possibility for outside air to enter or for the building to become negatively pressurized. When venting areas that have higher moisture (kitchens, bathrooms) keeping doors closed to prevent moisture from diluting into the rest of the indoor air can help in controlling the amount of moisture in buildings. Warming cooler surfaces, through increased space temperature or improving insulation, as well as increasing air circulation will prevent moisture problems in these areas. Heat recovery ventilators are becoming more popular in new, very tightly built homes, and reduce the heat loss and ensure a controlled level of ventilation. In crawlspaces, vapor barriers, such as 6-mil polyethylene films should be used to keep moisture from entering occupied spaces, and should overlap 12 inches or more, as well as extend 8-12 inches up the foundation wall.

Major Grouping: Building Assemblies
Subgrouping: Attics

R41) Manufactured Housing Research Alliance. “Attic Ventilation Design Strategies for Manufactured Homes”, 2003.

This article reviews the problems of moisture in manufactured homes, particularly in the attic.

Problems Encountered: Conventional building practices had stated that it was important to ventilate the attic space for proper moisture control. However, much of the research that led to this conclusion was based on cold climates, and the resulting practices applied to all climate types. In manufactured homes, as in all homes, attic design should not be a one-type for all solution. Though attic ventilation may work well in cold climates, it can have disastrous effects in warm humid climates. In these hot humid areas, it is often best to seal up the entire attic, to prevent moisture from outside from entering the building. Complex ceiling designs also make it more difficult to keep moisture out of attic spaces, resulting in incomplete air barriers, and include various types of planes, recessed lights, mechanical chases, and penetrations for plumbing, electrical and HVAC equipment.

Solutions Found: Full blown insulation used as a cover for variations in the ceiling plane, foam sealing of penetrations, and use of recessed lights rated for insulation contact can all help to reduce infiltration from more humid occupied spaces to cooler attic spaces. The most cost effective location for moisture and infiltration control and insulation may be at the roof plane rather than ceiling. All double-sectioned and shingled attics should be ventilated, and unvented attics can work in the appropriate climates, if designed and constructed properly.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R42) Prestemon, Dean R. “Minimizing Moisture Problems in New Houses”, Iowa State University Extension, April, 1994.

This article reviews the problems associated with moisture in houses, with an overview of all of the common areas for moisture intrusion, but with a focus on wood.

Problems Encountered: The main problems in wood framed houses caused by moisture intrusion include: the failure or deterioration of the exterior finish, decay due to fungi, excessive dimensional changes (expansion or contraction) of wood members, insulation getting wet, and the staining and deterioration of interior finishes. Rain and snow, soil, water from roofs and drain spouts and moisture condensation can all lead to these moisture problems.

Solutions Found: There are several steps to prevent these problems including using dry lumber, protecting wood during construction, keep out moisture from outside during construction, and control humidity in cold weather. Using natural wood products also reduces the potential for moisture damage. Pressure treated wood has maximized protection against mold, moisture, and insects. With foundations, install a vapor retarder on top of a gravel bed, but under the slab, whereas with crawlspaces use ground cover to minimize water evaporation from soil to underside of the house. Apply insulation to perimeter walls in crawlspaces if water pipes or heating ducts are in this area. For basement foundations, moisture penetration can be reduced by applying a coating. It is important to pay special attention to the portion of the basement wall that is above grade, and should be particularly well insulated. At least 8 inches of clearance between the ground and the bottom of any siding used should be allowed around the entire perimeter. To reduce moisture infiltration, it is important to seal joints around doors and windows, caulk and cap the outside of corner siding, and use appropriate flashing where two different types of sidings intersect. An overhang of 24 inches or more will help to reduce the impact of rain and wind driven rain on the exterior walls. Provide inlets at the lower areas of the attic, and outlet vents near the peak.

In summation, when proper care is used in selecting and installing wood construction members, moisture problems can be reduced, as well as minimizing maintenance. It is important to use natural wood products or ones treated with leach-resistant waterborne preservatives to reduce the problems of repeat exposure to water.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R43) Crosby, William. “The Basic of Moisture Problems-What to Look for and How to Fix It”, www.dhr.state.va.us, 2003.

This article reviews the problems of moisture in buildings, and how to solve these issues.

Problems Encountered: Moisture problems are caused by a variety of sources, but in older buildings leaky equipment and the use of the building are two of the most troublesome. In general, the five most common sources of moisture for buildings in general are: entering of exterior moisture due to deteriorating materials, ground moisture, leaky equipment, interior humidity, and water from maintenance and construction materials.

Solutions Found: Routine maintenance on both the interior and exterior of buildings should be performed. Roofing and guttering should be weather tight and operational. Low spots around the foundation should be eliminated, and downspouts boots should be cleaned twice a year, and make sure that water is always carried away from the building. Irrigation systems should be checked for leaks, as should hose bibs. For interior moisture problems, increasing ventilation is important to dilute moisture in the air. Ductwork and pipes should be insulated and sealed as necessary. For moisture problems, it is best to try to eliminate one potential source at a time.

Major Grouping: Building Assemblies
Subgrouping: Attics

R44) Iowa Energy Center. “Ventilation in Attics and Crawlspaces”, Home Series, 1998.

This article reviews the problems of moisture in residential attics and crawlspaces in buildings, and how to solve these issues.

Problems Encountered: In cold weather, much of the moisture that accumulates in attics comes from air leaks between the interior and the attic. In an unvented attic, moisture will not be able to pass through the roofing construction, and will be trapped in the attic, causing damage to materials.

Solutions Found: Proper ventilation is important to reduce the potential for moisture damage, which can lead to ice dams and other damage in the winter. The most effective way to control moisture in attic spaces is to seal the leaks in the ceiling, rather than rely solely on attic ventilation. Ventilation is necessary to provide adequate airflow through the attic, which, if vented properly through natural ventilation, fans are not needed. Crawlspaces that have utilities or pipes should have vents to the outside, to be opened in the summer and closed in the winter. These vents should be located at each corner of the crawlspace or basement.

Major Grouping: Building Assemblies
Subgrouping: Ventilation

R45) NAIMA. “Facts About Ventilation and Moisture Control”, Insulation Facts #11, #BI458, June, 1999.

This article reviews the problems of moisture in buildings, particularly the ventilation aspect applied to attics and crawlspaces and how to solve these issues.

Problems Encountered: The accumulation of moisture can lead to water stains, ice damage, blistering paint, the deterioration of wood, and the growth of mold and mildew. Moisture condenses on cooler surfaces and makes its way into building constructions.

Solutions Found: The three basic ways provided in the article on minimizing the potential for water to condense in attics, floors, and walls are: provide sufficient ventilation for interior humidity loads, ventilate sections to dissipate excessive humidity to outside, and use vapor retarders. In general, “passive ventilation is important for attics and crawlspaces, and mechanical ventilation is desirable for kitchen, laundries, and baths.” Vapor retarders can limit the movement of moisture from warmer to cooler areas in walls, ceilings, roofs, and even below floors. NAIMA recommends that each space have ventilation to the outside, and that openings are protected against rain and snow. Ventilators should not be obstructed, and insulation should be kept away from any soffit vents. In southern climates, crawlspace vents may not be necessary, since they can do more damage by introducing moist outside air into the crawlspaces. If vents are used, landscaping should not obstruct these vents. Vapor retarders should be located as close as possible to the warm-in-winter surface of the building. Good practice in construction usually calls for installing vapor retarders in the walls of all new buildings, and the use of separate vapor retarders with unfaced insulation is becoming more common. Again, the vapor retarders should face the warm-in winter side of the framing.

Major Grouping: Building Assemblies
Subgrouping: Ventilation

R46) Portland Cement Association. “Mold and Moisture”, Concrete homes Technology Brief #11.

This article reviews the problems of moisture and mold in concrete buildings, both homes and other building types.

Problems Encountered: The rapid pace at which the building practices and materials have progressed in the past century have led to problems in houses and buildings. Organic materials (paper faced drywall, plywood sheathing) are used commonly in practice, and provide an excellent food source for mold. With the increased energy efficiency of houses, making them more airtight, has led to uncontrolled moisture and humidity levels. The moisture comes from leaks and flooding, condensation, and air leaks.

Solutions Found: The most common solutions are proper ventilation, including exhausting excessive moisture to the outside, sealing outlets, sill plates, and any through wall penetrations to keep pressurization and reduce leakage, and regular inspection and maintenance of HVAC, roofs, windows, and siding, particularly after it has rained. The materials used in concrete buildings, foam, steel and concrete, are not food sources for mold growth. The interior finishes still are sources for mold to develop, and should be treated accordingly. Good construction practices, regular inspections, and preventative maintenance can be useful in preventing moisture problems.

Major Grouping: Building Assemblies
Subgrouping: Walls

R47) Klamke, Stephan E. “Moisture Intrusion Becomes a Growing Concern in Home Construction”, EIFS Alliance, 2002.

This article reviews the problems of moisture and mold in buildings in general, and those that use EIFS. The author states that it is poor construction practices that lead to moisture problems.

Problems Encountered: The author presents that it is not necessarily the type of exterior cladding, but the sound construction practices of that builders and contractors do not adhere to. Shoddy construction practices and inadequate flashing lead to moisture intrusion in wall cavities. Vapor barriers are often used when not appropriate, such as in wet coastal areas. Windows are also often the cause of moisture problems, but this again is due to poor installation. Newer walls are also prone to hold more moisture. Building paper can cause walls to not dry completely if a significant amount of moisture enters the wall cavity. Engineered wood products also have lead to moisture problems with their susceptibility to moisture. Finally, relying on unskilled work force on constructions sites.

Solutions Found: The use of vapor barriers should be evaluated on a state by state, or at least on climate, rather than as a blanket application. Moisture entry points must be adequately flashed and sealed, as well as properly installed and maintained. It is important to pay attention to details, use sound construction practices, and use only code-compliant application practices as well as high-quality, properly installed components.

Major Grouping: Building Assemblies
Subgrouping: Basement

R48) Ponessa, Joseph T. “Basement Moisture: Some Simple Remedies”, Rutgers Cooperative Extension, FS257, February, 2002.

This article reviews the problems of moisture in basements, causes and solutions.

Problems Encountered: High humidity in the basement area or the entry of water through various paths are two common forms of moisture problems in basements. Rainwater is an important problem in that it can cause foundation and basement wall problems and can enter exterior walls through capillary action. Having warm humid outside air into a cool basement, high water tables, and plumbing leaks are some of the most common water problems. If rainwater collects too close to the foundation, it can pool, and seep into the basement as water vapor or leakage. Channels can conduct surface water to small openings in basement walls, and are created by small leaks which erode soil and cause the pathways to grow. High water tables or lot situation (e.g. at the bottom of a hill) are harder problems, but can still cause damage if not addressed.

Solutions Found: Inspecting the exterior of a building right after a rainstorm can help in seeing where water is pooling near the foundation or basement wall, window wells, entry doors, and masonry slabs. The ground should not be sloped towards the house, but instead should be sloped ½” per foot for 10’ away from the house. Channels should be dug out and refilled, while regrading the surface. Small openings in the wall should be patched. High water tables and lot situations are more expensive to fix, and require the placement and use of sump pumps and perimeter drainage systems.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R49) Cram-Helwich, Amy. “Mold & Moisture: Builder Symposium”, Builders Association of Minnesota, December, 2002.

This article reviews the problems of moisture in homes and potential solutions. Included are comments from Dr. Joseph Lstiburek who spoke at the symposium

Problems Encountered: The increased energy efficiency of buildings has reduced significantly the ability for walls to dry, and the materials now used do not allow for any moisture storage, and instead cause damage to the materials and the construction. Materials now used are more prone to mold growth. Building codes in the United States do not currently account for regional differences (climate or location) either in temperature, humidity or rainwater. All reservoir claddings (brick, stucco, or wood siding) store water, plumbing is often located in exterior walls, and materials prone to mold growth (paper backed board) are placed in poor locations such as showers where they are likely to get wet.

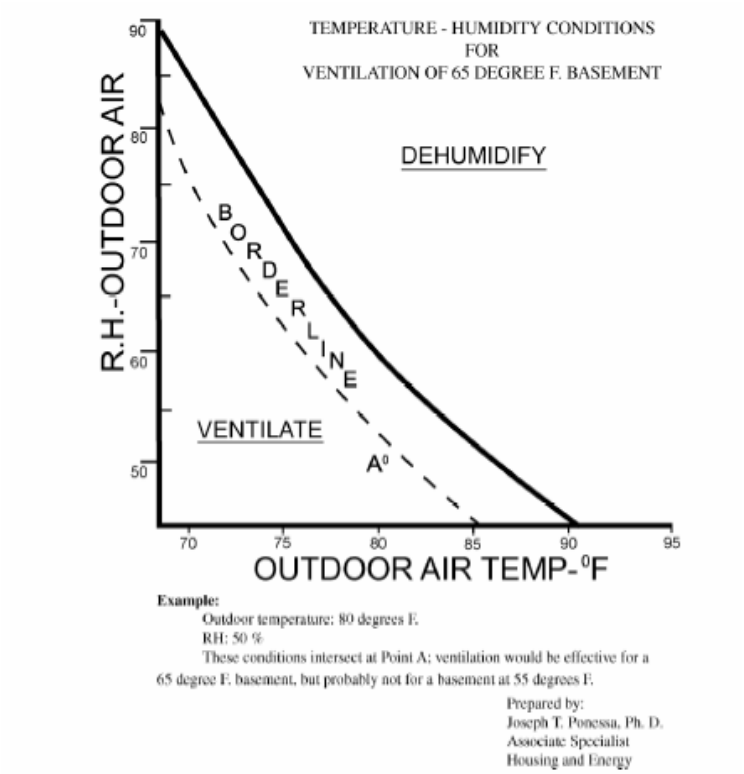
Solutions Found: Contractors should try to keep all building materials dry, but account for the fact that moisture does get in, and appropriate measures should be taken to dry them out completely and in a timely manner. Pan flashing is crucial to control moisture movement out of the building, regardless of cladding used. All reservoir claddings need to be well ventilated, so clear ventilation paths need to be in place in order to allow moisture to dry out. This can be done by furring out the reservoir cladding in order to disconnect it from the wall, or avoid them, back prime wood siding, and avoid polyethylene as a vapor retarder. It is critical that the basement be insulated on the exterior to allow any accumulated moisture to dry to the inside. Polyethylene air barriers and vapor retarders can help in reducing winter condensation, but can also increase summer condensation and mold growth in houses with reservoir cladding. The sheathing products used today are also less tolerant to moisture.

Major Grouping: Building Assemblies
Subgrouping: Basement

R50) Ponessa, Joseph T. "When to Ventilate the Basement to Reduce Moisture Problems", Rutgers Cooperative Extension, FS258, February, 2002.

This article reviews the problems of moisture in residential basements and how to determine if an area is prone to moisture problems, using a diagram.

Problems Encountered: There is no real standard as to when to ventilate or not ventilate basements with outdoor air.



Solutions Found: The above chart from the article presents when a homeowner should ventilate and when to dehumidify a basement. Drawing the relative humidity of outdoor air on the vertical axis, and the outdoor temperature on the horizontal axis, and where the lines intersect determines what is required. This is based on a basement that is at 65F, and the line will shift to the right if the basement is warmer, and to the left if cooler.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R51) Oregon State University. “Moisture Control Measures”, Oregon Residential Energy Code, #15, August, 1996.

This article reviews methods to control moisture in residential buildings, particularly for Oregon.

Problems Encountered: This article addresses what should be done as far a building codes, not specific problems.

Solutions Found: The vapor retarder should be on the warm side of insulation to prevent water vapor diffusion into the wall cavity, rated at 1-perm. Kraft paper installed above decking and below finish floor underlayment serves as vapor retarder, and slabs do not require vapor retarders. When there are attics, no vapor retarder is required for the ceiling below. Ground cover protects the house from ground moisture. Vapor retarders must be opaque so as not to promote plant growth.

Major Grouping: Building Assemblies
Subgrouping: Basement

R52) Schnabel Solutions. “Wet Basement…Got you Down?”, Vol. 1, No.2.

This article reviews factors that cause water problems, and potential solutions particularly for basements.

Problems Encountered: Below grade structures have a great potential for water problems. Even if the basement is dried during construction, does not mean that it will stay that way. Problems affecting basements include surface water infiltration, improperly installed foundation drains and changes in ground water levels. Improper installation or future defects in walls and slabs will also cause water problems.

Solutions Found: Long term water data from geo-technical investigations should be acquired to help design and determine the sub-drainage system needed. The amount of surface water infiltration should be limited, which can be done by providing a surface that slopes away from the house. Roof water should also be controlled, by properly installed and maintained downspouts. Also, landscaped watering devices should be kept away from buildings (not immediately adjacent).

Major Grouping: Building Assemblies
Subgrouping: Manufactured Housing

R53) Moyer, Neil. “Moisture Problems in Manufactured Housing”, Home Energy, 2002.

This article reviews moisture problems particularly in manufactured housing.

Problems Encountered: Moisture condensing behind impermeable surfaces can cause damage and mold growth. Impermeable materials often found in manufactured housing include vinyl flooring, vinyl wallpaper, and OSB to name a few. Problems are caused by interior temperatures that are below the dew point, oversized HVAC equipment, negative pressures across the building envelope, duct leaks, moisture movement through the floor assembly, inadequate moisture removal and vapor retarders in the wrong location. Short cycling of HVAC equipment does not allow for enough dehumidification, cooler interior temperatures cause more water to condense on interior surfaces, and large blower fans in oversized equipment can lead to enhanced duct leakage issues and depressurization of the building. Poor design and construction practices can cause leaks and holes at connection points and penetrations in the building. As ducts are often placed under the floor, air and moisture leak into the belly and eventually enough air can tear through the belly board. Closing doors can also change the pressure of spaces within the home.

Solutions Found: There are several recommendations to reduce the above listed problems, and include adjusting thermostats appropriately (not too warm in winter or too cold in summer), avoid negatively pressurized spaces and homes, seal all ductwork, provide adequate moisture removal, and eliminate ground source water by diverting water (roof and lawn drainage) away from the house. Adequate moisture barrier is needed for the floor assembly and the removal of vapor retarders from the wrong surfaces, or eliminating them in houses in the south.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R54) Crosbie, Michael J. “Building America: CARB News”, Vol 5, No 10, April, 2002.

This article presents a tool available to assess moisture in building assemblies.

Problems Encountered. Mold causes and researching moisture problems is becoming an increasingly important issue in the building industry.

Solutions Found: There is a program developed by Oak Ridge National Laboratories with Fraunhofer Institute for Building Physics called WUFI that is a moisture engineering assessment tool, to predict moisture and moisture movement in building assemblies. The software is able to predict the amount and movement of moisture and heat transport through the building envelope under a variety of climatic conditions. This simulation/modeling program can assist in studying the causes and potential causes for mold growth in building envelopes. The dynamic movement of water can be assessed through typical building assemblies of a 24 hour period or seasonally. It is currently used to evaluate the condensation potential on the interior side of exterior insulating sheathing in above-grade walls.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R55) Redman, Linda and Rachel Rowe. “The Billion Dollar Thief: Moisture”, Clemson Extension, Residential Housing, HL239, July 1991.

This article addresses moisture issues and problems that homeowners should be aware of and look for when buying or building a house.

Problems Encountered: Several important questions should be asked when buying or building a home, including how rainwater is managed from the roof (downspouts have backsplashes and gutters clean), on the ground (slope away from foundation and siding at least 6 inches above soil level) and landscaping (not blocking vents and at least 5 feet from side of house). By asking the right questions, potential moisture problems can be found ahead of time.

Solutions Found: Corresponding to the above questions, overhangs should be at least 18 inches wide, gutters should be in good shape and clean, and splashblocks should be correctly placed (at least 5 feet from foundation) and made out of durable materials (such as concrete or masonry). Landscaping is something of particular note, and often overlooked, as plants should not block vents for basements and crawlspaces, plants should be located beyond the drip edge of the roof, and the ground should be sloped away from the house. On the interior of the house, ducts should be insulated to prevent condensation, and air leaks (particularly at duct joints) be properly sealed. In humid climates foundation vents should be open year round, and if the vents are not sufficient to keep moisture levels down, then 6-10 mil polyethylene should be used to cover the surface of the crawlspace. If there are no gutters, then drip edge flashing should be used, overhangs should be at least 30 inches wide, and the ground surface should be covered with gravel to promote proper drainage. Flashing should be located underneath all windows and doors, wherever roofing meets siding, and the top of the foundation. In attics, it is again important to not have obstructions to the vents.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R56) Ryan, Sean "Residential Contractors Face Growing Mold Problem", Environmental Support Solutions, www.ess-marketing.com/articles/contractors5.htm.

This article addresses the building contractor's role in moisture problems and solutions.

Problems Encountered: Homeowners have become more aware of problems with moisture due to publicity, but the same types of mold are growing in houses. Moisture problems come from roof leaks, condensation, and damp basements or from lack of maintenance. As houses become more tightly constructed for energy efficiency standards, it is getting more difficult to bring in outside air. Leaving the roof (or parts of the roof) unprotected and not draining the basement before installation of the foundation also can cause serious moisture problems. Houses are also not necessarily well maintained.

Solutions Found: Putting in air exchanger in houses helps with the ventilation without contributing to mold problems. Builders should also stress the important of ventilating homes in the first two years of inhabiting it, as materials used need time to dry out. It is also important to educate the homeowner.

Major Grouping: Building Assemblies
Subgrouping: Mold

R57) Bode, Marilyn and Deanna Munson “Controlling Mold Growth in the Home”, Kansas State University, MF-2142, September 1995.

This article addresses the mold problems in the home and solutions to reducing the potential for this problem.

Problems Encountered: Mold thrives on organic materials, in warm temperatures, and requires moisture and oxygen to grow. For basements and crawlspaces, moisture can come from the earth, migrating through concrete walls in basements and due to firewood being stored. Crawlspaces that are incorrectly sloped or left uncovered can also have moisture problems. New construction materials, unvented combustion heaters, spill and leaks all can contribute to moisture problems in houses.

Solutions Found: There are several ways to prevent mold growth in houses; mainly keeping it clean and dry. Keeping surfaces and textiles dry and clean, by reducing moisture within the home, dehumidifying humid areas, and increasing the air flow. By installing adequate insulation, installing vapor barriers where appropriate and reducing the sources of moisture, mold growth can be prevented. This includes sealing cracks, sloping earth away from the foundation and using downspouts to direct water away from the house.

Major Grouping: Building Assemblies
Subgrouping: Walls

R58) Bower, John “Moisture Control and Brick Veneer”, Indiana Builder, November, 1993, p.15.

This article addresses the issues of moisture and the exterior cladding of brick veneer with potential problems and solutions.

Problems Encountered: The purpose of the airspace between the brick and wood framing is often misunderstood, and therefore not properly installed. The air space acts as a diffusion break to keep the wood dry. The airspace is often clogged by mortar droppings, which can cause moisture to diffuse through the droppings and into the wood members. Droppings can also clog weep holes, making pressurization of the wall and the exterior, which can increase moisture transport. Improper flashing can cause moisture to stay at the bottom of the wall cavity, rather than being transported to the exterior. With metal ties, if they are improperly installed, and sloping upward, they can direct water back in towards the wood.

Solutions Found: Airspaces need to be kept clear, and are sometimes increased from 1 inch to 2 inches to prevent the problems associated with mortar drippings. Properly installed flashing will direct water to the exterior of the wall construction, thereby keeping the moisture away from wood members. Metal ties need to be installed sloping downward, to carry water towards the brick and outside.

Major Grouping: Building Assemblies
Subgrouping: Windows

R59) Bower, John “Windows”, Green Alternatives, November/December, 1992, p.26.

This article addresses the issues of windows, and their role in moisture problems in buildings. It also presents and compares various window types.

Problems Encountered: Window types can have an impact on the temperature of the window surface and the moisture that can accumulate around the window. Aluminum frames can sweat in the winter, which can lead to mold growth.

Solutions Found: Airtight windows will result in less infiltration, and those windows made today are much more tightly constructed, which is good for energy efficiency and can increase the surface temperature of the window surface. Vinyl window frames are less expensive, aren’t subject to mold growth due to the materials used, and require no painting. Thermal breaks in aluminum frames can reduce, if not eliminate, the problem with moisture on the frame.

Major Grouping: Building Assemblies
Subgrouping: Walls

R60) Rousseau, M.Z., “Facts and Fictions of Rain-Screen Walls” Joseph. Construction Canada 32(2), 1990, p.40,42-44,46. Reprinted at www.irc.nrc-cnrc.gc.ca/practice/wal3_E.html.

This article addresses rain penetration through walls that ultimately damage the building envelope. A "rain-screen wall" is designed and built according to what Kirby Garden referred to as the "open rain-screen principle,"1 whose basic premise is the control of ALL forces that can carry rain to the inside of a structure.

Problems Encountered: Rain penetration is due to the forces acting on the exterior cladding of a building: gravity, surface tension, capillary action and raindrop momentum. A typical cavity wall can address these issues adequately. However, when the variable of air pressure difference across the cladding is introduced, the cavity wall is no longer sufficient.

Solutions Found: A pressure-equalized rain-screen wall controls all the forces handled by a drained cavity wall plus the air pressure difference acting across the cladding. If the wall design is proper, there will be no net pressure difference on the wall due to wind. One needs a rigid air barrier; a cavity behind the cladding broken down vertically and horizontally into tight compartments of varying sizes; a large venting area connecting the cavity to the outside; and a somewhat impervious cladding to ensure pressure equalization.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R61) Newey, Mark, “EarthCraft House Fights the Growing Mold Myths” The Southfac Journal of Sustainable Building, Summer 2004.

Problem Encountered: Mold is ubiquitous and a real concern for homebuilders. This article addresses several prevention measures.

Solutions Found: Allow for proper drainage. Water from roofs should be discharged a minimum of five feet from the building (with proper grading). Windows and doors should be properly flashed on all sides. A drainage plane of felt paper or wrap should be installed shingle-style underneath the brick or siding. Flashing that tucks under the bottom of the drainage plane and kicks water out completes a good drainage system.

Stop wicking. A material that will not allow water to wick from the foundation to the framing should be used (e.g. metal flashing or foam gasketing).

Exhaust moist air out of house. Exhaust fans should be present in kitchens and bathrooms directly vented to the outside, not the attic. Kitchen ranges should not be oversized.

Build houses airtight. Goal of 0.35 air changes per hour or better is suggested.

Insulate continuously. No voids or gaps that can create cold spots/condensation.

Don’t oversize Air Conditioners. Properly sized AC units will dehumidify better than oversized units.

Seal ductwork. Creates pressure imbalances and makes humidity control difficult.

If mold is present, water is present. Fix the water source issue before performing mold remediation.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R62) Cheple, Marilou and Pat Huelman. “Moisture Control in Bathrooms”, Home Energy Online, March/April 1998.

This article addresses the problems associated with moisture and moisture control in bathrooms.

Problems Encountered: The demand for comfortable, non-drafty, tighter homes has led to moisture problems, as builders can no longer rely on leaky houses to provide the necessary ventilation to prevent it. Improved building materials and methods, and energy efficiency have led to reduced airflow, and reduced the wall assembly’s ability to dry out. Before the tightening of houses, bathrooms, kitchens and the basement were the main areas of concern, which builders worked to correct and avoid leaks and major water issues. Now they must deal with moisture vapor and where it condenses. Dropped soffits, cantilevers and bays can challenge wall integrity.

Solutions Found: Builders must insulate, air-seal, and ventilate correctly; build tight, ventilate right is now a necessity. The most efficient walls have exterior finish, drain plane behind the cladding material, wind protection layer, full coverage insulation, appropriate structural system, air barrier, vapor retarder, interior wall finish material, and finish. Use high quality, energy efficient windows, good exhaust fans, and minimize usage of flexible duct.

Major Grouping: Building Assemblies
Subgrouping: Materials

R63) Conceptual Reference Database. “What Happens When OSB Gets Wet?”, Building Envelope Research, February, 1992.

This article addresses the problems associated with OSB (oriented strand board) and when it gets wet.

Problems Encountered: OSB can irreversibly swell, particularly at the edges when it comes into contact with a lot of moisture. This can lead to other problems in construction. It is very slow to dry out.

Solutions Found: OSB can handle some moisture without swelling, as it has wax and resins that are used to hold it together and protect it. OSB is bonded with waterproof adhesives, and absorbs water slowly. There are preservative treatments (such as zinc borate) used on OSB to reduce moisture and termite problems. It is important to protect the OSB from getting wet on the construction site, and is not recommended to be used in areas where it would be in sustained contact with moisture. OSB is always installed behind a moisture barrier.

Major Grouping: Building Assemblies
Subgrouping: Lighting

R64) Bennett, Susan and Horacio Perez-Blanco. “Air and Moisture Leakage Through Recessed Ceiling Light Fixtures”, Energy Design Update, January, 1994.

This article addresses the problems associated with the use of recessed (can) light fixtures and air leakage.

Problems Encountered: Typical recessed lighting fixtures leak approximately 1/3 of a gallon of condensed moisture daily into a cold attic, based on Penn State tests. These recessed light fixtures allow warm moist conditioned air to enter into colder attic spaces, where the moisture will condense. Air leakage varies from 2 cfm to 10 cfm per fixture, depending on the stack effect against the ceiling. The lamp wattage had little effect on the air leakage.

Solutions Found: There are ‘airtight’ recessed lighting fixtures that are available, for approximately $5 per fixture over the traditional recessed lights. In heating climates, this is recovered by the energy savings from the reduced leakage.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R65) Lstiburek, Joseph and John Carmody "Fundamentals of Moisture in Houses", Home Energy Magazine Online, November/December, 1995.

This article addresses the issues of moisture in houses-for both heating and cooling climates-and potential solutions.

Problems Encountered: Mold grows on interior surfaces in heating climates and in cooling climates, but due to cold exterior temperatures in heating climates, and cold interior conditions in cooling climates. Impermeable wall coverings make the problem of moisture worse because it is trapped between the finish (vinyl wall paper) and the gypsum board. Carpets can hold mold when located on a cold surface, such as a concrete slab in a basement.

Solutions Found: Homes should be kept slightly positively pressurized, and an exterior vapor diffusion retarder should be used in cooling climates. Airtight assembly helps in keeping buildings positively pressurized. Insulating between the slab and the carpet will reduce the risk of problems with dust and mold in basements. Other important measures include increasing surface temperatures and reducing moisture levels. It is also important to know which factor dominates in order to solve the problem. Possible solutions include using setback thermostats, but an appropriate balance between reducing energy consumption and avoiding surface moisture problems, not closing off rooms, which can change the pressure balance, and insulating problem areas. Problem areas include exterior corners and exterior wall-roof intersections. For air conditioned spaces, possible solutions to moisture issues include controlling the air pressure differences and leakage openings, eliminating cold spots, increasing surface temperatures indoors, and increasing the ability of the interior finish materials to breath in hot humid climates. Caution should be used because adding insulation can reduce the temperatures of the outer wall assembly, which can cause hidden condensation problems. This can be done by raising the temperature of the interior surface or reducing the amount of water that enters the wall cavity. Higher-performance windows can lead to more moisture problems in heating climates because condensation does not appear on the windows-warning of excessive moisture.

Major Grouping: Building Assemblies
Subgrouping: HVAC

R66) Garrett, Doug "Better Breathing Thanks to Good Science", Home Energy Magazine Online, 2002.

This article addresses the issues of moisture and mold problems as caused by oversized HVAC and leaky ducts.

Problems Encountered: Oversized air conditioning equipment can cause short cycling, when the air conditioner only turns on for a few minutes at a time, not having enough time to dehumidify the air, and allowing humid outside air to enter. In the short period that the air conditioner is on, it can cool the house, but does not get cold enough to dehumidify. The excess moisture that then enters the house can cause mold growth. Leaky ducts, which are very common, exacerbate this problem.

Solutions Found: By adequately sizing the air conditioning equipment, the unit then runs at full load for more of the time, eliminating much of the short cycling, and allowing dehumidification to take place. Seal the leaky ducts and use the appropriate sized air conditioning equipment and moisture problems are significantly reduced. It is important to address the system, and not just one single item, in order to control moisture in homes.

Major Grouping: Building Assemblies
Subgrouping: HVAC

R67) Krigger, John "Sealing Up Your Home's Leaks", Home Energy Magazine Online, 2002.

This article addresses the issues of moisture and the leakage within homes as a cause of mold problems and offers potential solutions.

Problems Encountered: Recessed can lights need ventilation due to the fire hazard created with the elevated temperatures, which allows conditioned air into the attic. Stairways to basements or attics that are unconditioned are like large holes. Unused central heating chimneys have the ability to pull conditioned air from the home and depressurize the building.

Solutions Found: In cold climates, the house is more humid in the interior, so it is better to seal air leaks from the inside. Air barriers should be on the inside surface of exterior walls. In warm climates, the air barrier is better placed on the building's outside surface. The biggest leaks should be sealed first. Recessed lights should use fluorescent lamps, which do not need the venting that incandescent lamps do. It is important to choose air sealing methods and materials to seal up leaks based on the size and location of the leak, how accessible it is, the air pressure that it will need to resist, and the compatibility of the sealing materials with surrounding materials.

Major Grouping: Building Assemblies
Subgrouping: Manufactured Housing

R68) Tsongas, George "Moisture and Mobile Home Weatherization", Home Energy Magazine Online, July/August, 1995.

This article addresses the issues of moisture particularly in mobile homes, and the problems with weatherization as well as offering possible solutions.

Problems Encountered: Vapor barriers or retarders placed on the exterior of wall cavities can cause moisture problems in heating climates. Weatherization can exacerbate humidity problems. Newer homes have vapor retarders on the inside of the wall cavity, whereas older homes had the vapor retarder on the outside of the wall cavity. Exterior vapor retarders trap moisture that is migrating through the wall cavity from the inside to the outside. During the winter, or cold weather, the vapor then condenses on the inside surface of the vapor retarder, drains to the bottom and collects. This can cause wood members to decay. High indoor levels of humidity have been attributed to the decay of walls, trapping moisture in the walls, and preventing it from drying out. Tightening the building envelope reduces the natural ventilation rate, thereby increasing indoor humidity levels. Many Weatherization methods increase the tightness of homes.

Solutions Found: Homes in the Pacific Northwest that do not have exterior vapor did not have evidence of wood decay. It is recommended that the exterior vapor retarder is removed, or removed and replaced with a permeable barrier, or cutting the retarder open at the bottom of the wall cavity. Weatherization of homes that do not have an exterior vapor retarder should be done as planned.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R69) Washington State University "Indoor Air Quality Factsheet: Keeping Homes Dry", WSU Cooperative Extension Energy Program, WSUCEEP2002-066, January, 2003.

This article addresses the issues of moisture in homes and solutions to keep homes dry.

Problems Encountered: The weather cannot be controlled, and excessive moisture can cause homes to potentially have structural problems. Renovation, damaged materials, peeling paint and staining are all associated with moisture problems.

Solutions Found: First it is important to keep moisture out of homes, but checking for roof leaks, having water shed away from the foundation and crawlspace, and checking that gutters, downspouts and landscaping direct water away from the house. Secondly, the amount of moisture inside should be controlled, by exhausting excess moisture outside, exchanging moist indoor air for fresh outside air, and keep rooms and the house warm. Whole house systems should be on clock timers to keep the home adequately ventilated and limit the humidity levels based on the seasons, climate, and moisture levels. Digital gauges are also available to alert residents to increased moisture levels.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R70) Boyko, Bohdan "Moisture in Houses", Green Fiber, September, 2001.

This article addresses the issues of moisture in houses and the differences between climates with some solutions.

Problems Encountered: There are several interacting mechanisms that can impact and prevent moisture problems in buildings, including airflow, moisture flow, and biological and chemical reactions. Climate, construction practices, construction conditions, building envelope design, and building operation all can contribute or prevent moisture issues in buildings. In the past 50 years, buildings have become more tightly constructed, more insulated, no more active chimneys, and have forced air heating and cooling systems. Duct leakage can cause condensation and pressure differences, which impact heat, air and moisture flows. More tightly built houses have lowered air exchange rates, but the same if not more moisture generation that leads to the potential for additional moisture problems.

Solutions Found: We can control the moisture in buildings, which is one of the necessary things for mold to grow. Bulk moisture through leaks and pooling are quickly noticed, whereas vapor movement is more difficult to track. Airflow can be managed with proper air sealing, vapor retarders, and pressures. Controlled ventilation is also necessary, especially in tighter, better-insulated houses.

Major Grouping: Building Assemblies
Subgrouping: Manufactured Housing

R71) Taylor, John "Indoor Air that can Injure of Kill: The True Story of Manufactured Housing Indoor Air Quality", Manufactured Homeowners' and Homebuyers, 2001.

This article addresses the issues of moisture problems in manufactured homes and the legislation that is applied to them.

Problems Encountered: Manufactured housing does not have to meet federal standards, and performance and basic requirements are not regulated. There is no need for a professional engineer or architect to sign off on plans, and these homes are not necessarily in compliance with widely accepted engineering practices. There is a proposal to have a waiver that removes the blame for condensation problems that leads to rotting manufactured homes from the manufacturers. There is a preoccupation with controlling costs as the first and foremost constraint with manufactured homes. By not imposing standards, then these homes can remain at low cost. Moisture is one of the biggest problems in manufactured homes, and has been presented as if the HUD-code caused the moisture problems, when in fact it is the manufacturers ignoring standards. Vapor barriers are improperly designed and located, and attention is not paid to the climate to which the home will be delivered. One big problem with mobile and manufactured homes is duct leakage, and the location of the ducts in the belly boards, which can deteriorate due to the build up of moisture. To reduce costs, if floor joists are 5 ½ inches, only 3 ½ inches of insulation is used, leaving a cavity between the floor and insulation, where warm moist air can enter. Unfortunately the HUD-code does not require that this void be completely filled. Vinyl covered gypsum is used as a primary interior wall covering, it is low cost, but is vulnerable to moisture.

Solutions Found: The author determines that it may be better for manufacturers to actually follow the code, rather than focusing on the lowest cost option.

Major Grouping: Building Assemblies
Subgrouping: Roofs

R72) Sweet, Kimberly "What Goes Under What's on Top", Housing Zone, October, 2003.

This article addresses the issues of moisture and the leakage within homes as a cause of mold problems and offers potential solutions.

Problems Encountered: The author suggests that workers should pay attention to preventing moisture intrusion as much as they do to framing and shingles. Roofing systems shelters the house, people, and materials from the elements outside, and withstands the loads from the interior. Penetrations in the roof are the most prone to leakage.

Solutions Found: Roofing felt and flashing help prevent bulk moisture from entering. However, different climates and materials mean that appropriate roofing felt should be selected based on these. Roofing felt layers should be overlapped appropriately to keep water out, and go over the drip-edge eaves flashing, and under the drip-edge flashing on the rake or side. If flashing is installed properly, it will direct water towards the exterior and away, rather than allowing moisture to seep in and get under the roofing felt. Ceiling openings should be sealed to prevent leakage between attic and living space. Objects or insulation should not block vents in the attic, eaves, and crawlspaces. By increasing the insulation and ventilation in the attic, the potential for ice dams can be significantly reduced. For sheathing, panels should have 1/8 inch space around, nails should hit a support, and panels should go perpendicular to the supports.

Major Grouping: Building Assemblies
Subgrouping: Windows

R73) Walker, Richard "Don't Become a Victim of Burgeoning Mold Lawsuits", Door & Window Maker Magazine, November/December, 2003.

This article addresses the issues of moisture particularly with windows and for window manufacturers.

Problems Encountered: Condensation and water leakage leads to excessive moisture accumulation indoors. Leaky windows are less likely to cause moisture problems than are ventilation and HVAC, leaky roofs, dripping pipes, and poorly-sealed basements. When windows leak, it is usually due to the product being mishandled in the field, or poor installation, rather than poor manufacturing.

Solutions Found: Windows and doors that meet code requirements (e.g. ANIS/AAMA/NWWA etc) are "effectively resistant to water leakage under typical usage conditions." Condensation is reduced with windows that are thermally efficient (based on NFRC 100 and NFRC 500 standards), and therefore resistant to condensation. It is important to control installation as much as possible, control shipping and handling, test the product at shipping dock on a daily basis for quality control, and watch the performance of wood and composite materials.

Major Grouping: Building Assemblies
Subgrouping: Materials

R74) Merry, Jack "It's the Moisture, Stupid", Housing Zone, June, 2000.

This article addresses the issues of moisture and how wood products are being unreasonably targeted.

Problems Encountered: Composite wood products have been blamed for building envelope performance problems. Wood products are being exposed to long-term moisture more and more often. Houses today also have more corners, slopes, nooks, and other design features that require proper detailing and workmanship to keep weather and water out. The author also states that there is a growing shortage of skilled construction workers. Interior condensation problems are exacerbated by the energy efficient, sealed houses that are built today due to code requirements.

Solutions Found: Wood does in fact decay, but are a good product when it comes to energy efficient, environmentally sustainable product with low maintenance and operation costs and good strength and durability. The solution is to prevent moisture intrusion in the first place, through proper building practice.

Major Grouping: Building Assemblies
Subgrouping: Walls

R75) McLeister, Dan "Uncertainties Continue About EIFS Water Damage", Housing Zone, June, 1999.

This article addresses the issues of moisture with respect to the Exterior Insulation Finishing System (EIFS) and the bad reputation that it has received. It also distinguishes the two types of EIFS.

Problems Encountered: EIFS has had a bad reputation in the past few years, due to moisture problems. However that was with the old face sealed barrier type system. This type resists water penetration at the exterior surface, but does not allow water to drain or dry out once it has gotten behind the exterior stucco, it has no rainscreen. The lack of a drainage cavity, and lack of weather resistive barrier, and limited drying potential all cause problems with moisture in this type of EIFS. Windows are the most common place to have water intrusion through seams and joints. Moisture damage seems to be concentrated in wet, coastal areas.

Solutions Found: There is a water managed EIFS that perform effectively, and can handle water that penetrates the exterior surface. Because building paper was installed, any moisture that gets through the exterior surface is then stopped at the building paper and taken down and out of the wall through flashing and weep details. A sheathing membrane that is in the wall construction keeps water from moisture sensitive materials.

Major Grouping: Building Assemblies
Subgrouping: Roofs

R76) Legg, David Connelly "Beauty and the Beast Upstairs", Home Energy Magazine Online, March/April, 1995.

This article addresses the issues of moisture and leakage problems in roofs-particularly half-story spaces above the primary occupied space.

Problems Encountered: Architectural details at the roofline can cause major problems with moisture and heating. This includes knee-walls, dormers, side attics, top attics, and sloped ceilings, which can have air leakage and insulation problems. Heated air flows through joist cavities into the attic when blocking is not installed to seal the joist cavity beneath the knee-wall. Batt insulation does not block airflow, but only slows airflow in or near the floor/knee-wall transition.

Solutions Found: It is important to control moisture through source control, mechanical ventilation, and proper use of air and vapor barriers. It is key to line up the pressure boundary with the thermal boundary of the house. The pressure barrier prevents the infiltration of outside air and exfiltration of inside air. The pressure boundary should be on the warm side of the insulation, and inline with the thermal boundary. Also, sealing the leaks at the floor/knee-wall transitions and other key junctures makes sure that the pressure boundary is kept in line with the insulation. Knee-walls should be insulated; wall cavities should be sealed at wall and ceiling junctures, and sloped side attics should have a rigid air barrier.

Major Grouping: Building Assemblies
Subgrouping: Walls

R77) Tooley, John “Handling Framing Details in High-Performance Homes”, Home Energy Magazine Online, May/June, 1999.

This article addresses the issues of details and how they can lead to moisture and leakage problems if not properly attended to in homes.

Problems Encountered: Houses are not simple box designs, so there are difficult corners, holes, protrusions, and gaps that have to be properly sealed and bridged. Dropped ceilings, chimney cavities, and other framing details offer a potential to allow air leaks into attic areas.

Solutions Found: The builders and designers need to work together as a team to create a properly installed thermal and air barrier-the “continuous contiguous complete (3C) barrier”. The protrusions into the attic should be capped with a sheet product such as oriented strand board. The cap should be air sealed with caulk, foam or a gasket for wiring, plumbing, or venting penetrations. The interior cladding is used as the 3C location in cold climates, while the exterior sheathing is used in warm climates. Using the 3C barrier in the proper location can reduce air infiltration, hidden condensation, and mold growth. The location of the air barrier will establish the location of the vapor retarder and the thermal barrier.

Major Grouping: Building Assemblies
Subgrouping: Materials

R78) Horner, W. Ellliot, Philip Morey, and Bryan Ligman. "How Quickly Must Gypsum Board and Ceiling Tile Be Dried to Preclude Mold Growth After a Water Accident?" ASHRAE IAQ 2001.

This article addresses moisture problems in gypsum board, and the time frame in which the wall must be dried out to avoid moisture and mold problems.

Problems Encountered: Gypsum board is generally susceptible to deterioration, as they are not intended to become wet, and often become infested with mold first. Tests were performed in a controlled environment to determine the growth rate of mold at various relative humidity levels while the board was drying out.

Solutions Found: Mold growth could occur in as little as 48-72 hours, and after seven days at 50% relative humidity, mold had visibly grown. Mold tended to grow first in the pits of ceiling tiles and at the cut edges of the sample pieces. It is the amorphous cellulose (such as the paper fader of gypsum board) that is particularly subject to mold growth. Still air, such as that found in wall cavities, favors the development of mold. Significant mold growth occurs in one to two days, which supports the conventional wisdom that after a water problem, the house must be dried out within two to three days to prevent mold growth. Again, these experiments were performed in a laboratory setting, with still/static air.

Major Grouping: Building Assemblies
Subgrouping: Moisture

R79) Tsongas, G. “A Field Study of Indoor Moisture Problems and Damage in New Pacific Northwest Homes”.

This article addresses moisture problems and related damage through case studies in homes in the Pacific Northwest.

Problems Encountered: Moisture problems were identified in newly constructed homes, particularly with respect to ventilation systems to determine if building to more energy efficient standards with more insulation and relatively air tight vapor barrier caused indoor moisture problems. Indoor surfaces such as walls and window frames and/or sills were found in one third of the homes, while 75% had moisture on the window glass and frames, and 25% had window sill damage as a result of window condensation. The main reasons for this included inadequate dehumidification and exhaust fans that were not installed, or not working properly. Bedrooms were often a problem area, as they are kept at cooler temperatures, so have higher relative humidity levels.

Solutions Found: It is important to have better indoor moisture control, particularly for future tightly built homes, moisture control must have a high priority through better ventilation, automatic control and dehumidification. It is recommended that portable dehumidifiers be used, as ventilation systems either do not work properly, or do not adequately dehumidify the air. For air tight homes, it may be necessary to install automatic moisture controls, as they seem to be more prone to moisture problems.

Major Grouping: Building Assemblies
Subgrouping: Airtightness

R80) Sherman, Max and Darryl Dickerhoff. “Airtightness of U.S. Dwellings”, ASHRAE Transactions, 1998, Vol 104, Pt. 2..

This article addresses the airtightness of residential buildings in the United States and leakage characteristics by region, age, and construction type. Results are based on the compilation of a variety of databases across the U.S., but not from every state.

Problems Encountered: Multi-story houses are 11% leakier than single story houses. Houses that did not have crawl spaces or unconditioned basements were 5% tighter than those that did. Houses built after 1980 were tighter than average, though still relatively leaky. Houses that had duct systems were tighter than those without duct systems.

Solutions Found: Retrofits of homes reduced the leakage by 25%.

Major Grouping: Building Assemblies
Subgrouping: Airtightness

R81) Merrill, J.L. and A. TenWolde. "Overview of Moisture-Related Damage in One Group of Wisconsin Manufactured Homes", ASHRAE Transactions, 1989, Vol 95, Pt. 1.

This paper addresses a large group of manufactured homes known as the Tri State Homes. More than 5000 were built with 3400 installed in Wisconsin.

Problems Encountered: After the manufacturing company went bankrupt, reports of extensive wall wood decay were reported in 1986 and later. Inspections of the homes revealed the homes were very airtight and poorly ventilated (no exhaust fans) leading to high indoor humidity levels resulting from internally generated moisture. Mold inside the homes was common, as were respiratory problems among the occupants, apparently due more to the high level of several pollutants rather than the presence of fungal spores.

Solutions Found: Ventilate moisture producing locations – bathrooms, kitchens, and laundry.

Major Grouping: Building Assemblies
Subgrouping: Manufactured Housing

R82) U.S. Department of Housing and Urban Development
http://www.hud.gov/library/index.cfm

This website presents problems and solutions, particularly for manufactured housing. They have produced studies in wall construction, HVAC, roofs, and attics, which have resulted in reports and guides for manufactured housing. One of note is “Alternatives for Minimizing Moisture Problems in Hot, Humid Climates” (from Texas to North Carolina), where selected buildings were diagnosed through surveys and field tests in order to create neural network modeling. HUD has created a Moisture Problems in Manufactured Housing handbook (http://www.huduser.org/Publications/PDF/moisture.pdf), and supports the development of an in-situ moisture content sensor with NIST. Two other guides of note are “Durability by Design: A Guide for Residential Builders and Designers” (http://www.huduser.org/publications/destech/durdesign.html) and “Building Concrete Masonry Homes: Design and Construction Issues” (http://www.huduser.org/Publications/PDF/masonry.pdf)

HUD with the Partnership for Advancing Technology in Housing (PATH) has several publications that list current and past research projects, including the “Field Test of Advanced Duct-Sealing Technologies within the Weatherization Assistance Program”, “Mold and Mildew on Wood: Causes and Treatment”, “Protecting Wood from Humidity” and “Water Intrusion Evaluation for Caulkless Siding, Window, and Door Systems”. (http://www.pathnet.org/sp.asp?id=1027)

Major Grouping: Building Assemblies
Subgrouping: Moisture

R83) Manufactured Housing Research Alliance. “Alternatives for Minimizing Moisture Problems in Hot, Humid Climates: Appendix E: Literature Review”. (http://www.huduser.org/Publications/pdf/MoistureReport_APP_E-LITERATURE_REVIEW.pdf)

This portion of the report presents a good literature review of a wide variety of articles for moisture problems. Much of the research and reports are from Canada and cold climates, many of the articles are general guidelines for all buildings. Many studies (including field studies) have been conducted to evaluate the performance of wall assemblies and construction details. Field studies include: walls insulated without vapor barriers, airtightness, air barrier construction details, infiltration and leakage in energy efficient houses, diffusion and infiltration of moisture in concrete masonry walls, as well as EIFS, windows, and rainscreen tests. There are also several computer analyses of moisture in building assemblies, including: moisture accumulation in roof cavities of manufactured housing, in wood frame walls, and in typical walls.

Several of the articles come from NIST and their publication library of moisture and moisture control in buildings. (http://fire.nist.gov/bfrlpubs)

Major Grouping: Building Assemblies
Subgrouping: Moisture

R84) ASTM Manual 18, Manual on Moisture Control in Buildings, Editor Heinz Treschel, 480 Pages, American Society of Testing and Materials, Philadelphia, 1994.

Manual consolidates lab/field data and applicable state-of-the-art technologies/techniques related to moisture problems in buildings: their diagnosis, prevention, and remediation. It provides information on how to design and maintain moisture-resistant buildings and how to investigate and correct moisture problems in existing buildings. It addresses residential, commercial, and institutional buildings in all North American climatic zones.

Manual is organized in 4 parts:

• *Part 1 Fundamentals* provides fundamental information and data relating to moisture control and the effects of moisture on buildings.

• *Part 2 Applications* discusses the application of related technologies to prevent or solve moisture problems in buildings.

• *Part 3 Construction Principles and Recommendations* gives guidelines and recommendations for designing and constructing new buildings and for increasing the moisture resistance of existing buildings.

• *Part 4 Implementation* provides insights into the various mechanisms for implementing moisture control strategies.

Additional text on standards and codes, contract documents, and legal aspects of moisture control aid in understanding the logistics for effective implementation of moisture control strategies. A short bibliography of useful reference publications is provided at the end of the manual.

Excerpted from http://www.astm.org/cgi-bin/SoftCart.exe/BOOKSTORE/PUBS/30.htm?L+mystore+mepi5654 .

Major Grouping: Building Assemblies
Subgrouping: Moisture

R85) ASTM Manual 40, Manual on Moisture Analysis and Condensation Control in Building Envelopes, Editor Heinz Treschel, 192 Pages, American Society of Testing and Materials, Philadelphia, 2001.

This manual provides an introduction to moisture analysis in buildings and examines the necessary technical background for conducting moisture analysis as an integral part of building design.. For the building practitioner without a deep knowledge in hygrothermal analysis, it offers a basic understanding of the mechanisms involved in moisture movement, condensation, and accumulation, as well as the tools for conducting analysis on simple building walls and roofs. For the intermediate and expert in moisture analysis, it adds recent state-of-the-art information on weather data, material properties, and an overview of single and multidimensional analysis models.

Also included is an accompanying CD-ROM with four programs. The first two are programs for converting properties of moist air: one, an excerpt from the Trane Toolbox program, is based on inch/pound units; the second, is a Danish program which uses dual units, SI, and a different version of inch/pound units.

The third and fourth programs are examples of moisture analysis models, MOIST and WUFI ORNL/IBP, which provide the reader with hands-on practice in the conduct of moisture analysis

Manual topics include:
• Moisture primer addressing hygrothermal mechanisms
• Weather and material data and failure criteria
• Analysis methods
• Manual methods
• MOIST and WUFI ORNL/IBP models
• Future trends
• Glossary of terms used in moisture analysis

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