A California Builder's Guide to
Reducing Mold Risk

A report to the California Energy Commission

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LEAD AUTHORS:
Lew Harriman - Mason-Grant Consulting
Neil Leslie - Gas Technology Institute

MANAGED BY:
Neil Leslie, Project Manager
Gas Technology Institute
1700 South Mount Prospect Road
Des Plaines, IL 60018
847-768-0926 Neil.Leslie@gastechnology.org

PREPARED FOR:
Ann Peterson
PIER Buildings Program Manager

PREFACE

The research project which generated this report is titled "Energy-Efficient Mold-Resistant Building Materials and Construction Practices for New California Homes." The project resulted from a concern that mold in residential construction has become a prominent public issue in recent years, and that mold problems may have implications for energy consumption. The people of California funded this project under the PIER program (Public Interest Energy Research), which is administered by the California Energy Commission on their behalf.

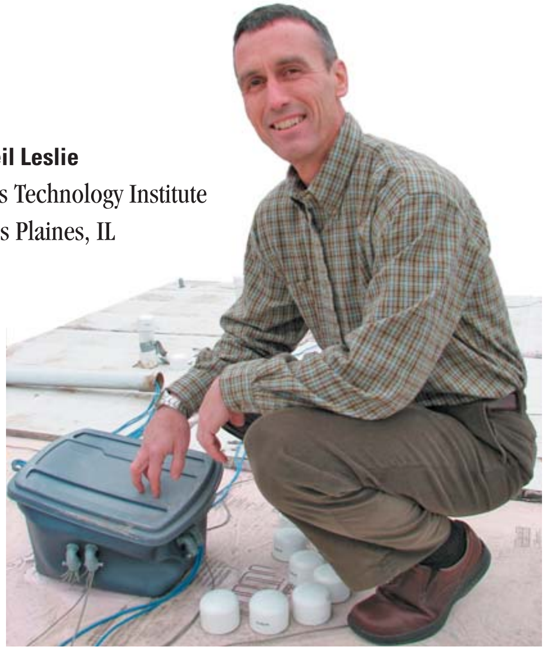
The majority of the project tasks consisted of laboratory and field studies of building assemblies which are important to keeping building materials dry, and therefore free of mold growth. The results of that research are published in great detail in other reports. In addition to that work, the project team was charged with providing a report to the California Energy Commission to include not only the results of the research, but also the current understanding of experts about ways to prevent mold problems in new residential construction.

This document is that report. It consists of the opinions and judgements of a wide variety of experts. These go well beyond the specific topics researched during this project. With that in mind, we ask the reader to consider this report simply a good beginning rather than the last word on this highly complex topic. It's also useful to keep in mind that this report has no force of regulatory authority. It simply represents the judgements of the authors about what currently constitutes useful advice to developers, designers, builders and owners about how to reduce the risk of mold growth in new California homes.

We dedicate this report to the people of California, and to the construction professionals and research colleagues who have made this work possible. This report is for you, with our greatest respect.

Lew Harriman
Mason-Grant Consulting
Portsmouth, NH

Neil Leslie
Gas Technology Institute
Des Plaines, IL



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The authors would like to acknowledge the generous support and contributions of the individuals below, without whom this project could not have been accomplished. The reader should also note that where there are errors in this report, the contributors are in no way responsible. Also, our contributors may not necessarily agree with all suggestions and all wording in this report. The subject is complex, and technical experts seldom concur on all points.

PROGRAM AND CONTRACT MANAGEMENT

Nancy Jenkins, P.E., Manager, Energy Efficiency Research Office
Ann Peterson, PIER Buildings Program Manager
Martha Brook, P.E., Senior Mechanical Engineer
Phil Spartz, Commission Contract Manager
Eric Stubee, Project Manager, SAIC

PROJECT TEAM

Neil Leslie, P.E., Gas Technology Institute
Lew Harriman, CMR, Mason-Grant Consulting
Doug Beaman, Douglas Beaman Associates
Carl Bergstrom, Magus Consulting
Charles Eley, FAIA, P.E., Architectural Energy Corporation
Doug Kosar, Energy Center, University of Illinois at Chicago
Bud Offermann, P.E., CIH, Indoor Environmental Engineering

PROJECT ADVISORY COMMITTEE

Doug Bibee, The Dow Chemical Company
Cordell Burton, The Pella Corporation
Pamela Davis, RN, PHN, California Research Bureau
Steve Easley, S.C. Easley & Associates
Barry Hardman, National Building Science Corporation
Darren Hudema, MWR, Dri-Eaz, Inc.
Claudia Lezell, Flooring Technology Institute
Don McNeill, California Department of Insurance
Jim Miyao, Sempra Energy Utilities
Frank Nunes, Lathing and Plastering Institute of Northern California
Mel Rasco, The Dow Chemical Company
Susan Raterman, CIH, The Raterman Group, Ltd.
Linda Schieffelin, Clarum Homes
Paul Shipp, Ph.D., P.E., USG Corporation
Charlene Spoor, Pacific Gas and Electric Company
Damon Tanaka, John Laing Homes
Jed Waldman, Ph.D., California Department of Health Services
David Ware, Owens Corning
Theresa Weston, Ph.D., DuPont Nonwovens

PARTICIPATING BUILDERS

Clarum Homes
John Suppes, Vice President
Linda Schieffelin, Senior Purchasing Agent
Jimmy Blackwell, Field Superintendent

John Laing Homes Inland Division
Victor Goochéy, Vice President Operations
Damon Tanaka, Purchasing Agent
Joe Vargas, Field Superintendent

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John Banta, CMR, Restcon
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Bill Weber, Four-Star Restoration

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Section 1

Summary

Fig. 1 Mold in new construction

You can reduce the risk of mold by making decisions during all phases of the project which reduce the probability of rain leaks and moisture accumulation.

SUMMARY

Avoiding mold in buildings is simple in principle: If you keep everything dry, mold cannot grow.

But we build our homes outdoors. And all buildings leak both air and water. Some leak more than others, and some climates are wetter than others, but water leakage and internal condensation occur in all buildings. So given time, the odds favor some things getting wet indoors, eventually. This in turn means that most buildings have some risk of having a mold problem.

This report describes a three-part strategy to reduce mold risk. The strategy is based on an understanding of mold problems in California houses and how such problems can be avoided:

1st. **Keep most of the water away** from the house through a few critical landscaping and drainage decisions made by the developer, designer, builder and owner.

2nd. **Keep the rest of the water out** by ensuring the roof, walls and foundation shed and exclude water consistently, while draining it away from the house.

3rd. **Limit mold growth while moisture dries out**, by stopping water leaks and spills from spreading indoors, and by choosing materials and assemblies which are less prone to moisture retention or mold growth when challenged by occasional wetting.

It's all about risk reduction

In the same way that a three-legged stool stands by itself and a one-legged crutch does not, this three-part strategy recognizes that in the real world, no building has ever been perfectly free from water intrusion. Based on that track record, the best bet is that buildings won't suddenly become perfect in the future–which is why a three-part strategy is more practical and reliable than assuming perfection in excluding water.

Several aspects of the strategy require thinking and planning well ahead of those harried, confusing but critical moments of decision when things either get built as you want... or in ways you regret.

Many of those critical moments occur at the earliest stages, when the owner and developer make their first aesthetic and budget decisions. These decisions make it easier or more difficult for the designer and builder to reduce the risk of mold.

It's useful to keep in mind that most buildings don't have mold problems. According to a nationwide survey of new and existing residential construction, fewer than 25% of homes have defects that could lead to moisture instrusion.[1] Most of these potential problems can be dealt with by cooperation between developer, designer, builder and owner. In California, only about 3% of new buildings have problems that reach the level of an insurance claim.[2] So it's clear that with some thought and care, buildings can be designed and built in a way that reduces mold risk. It's not that difficult, and it's being done every day, in spite of–or sometimes because of–competitive pressures.

This report provides some suggestions for how builders can choose a less risky path to profits and to customer satisfaction. It also provides an overview of mold-avoiding design choices for an owner, who probably prefers to invest in a home which increases in value, rather than in one likely to end up in litigation.

It's our choice...
Building codes don't prevent moldy buildings

It's important to realize that with few exceptions, the suggestions in this guide are not required by law. Currently, no federal, state or local building code provides any assurance that a building will not grow mold. The decisions which make a building either fragile or robust with respect to mold are, for the present, in the hands of the owner, developer, designer and builder.

In many cases, these suggestions do not add cost. They simply encourage making decisions consciously, in light of what's been demonstrated to discourage moisture accumulation and mold growth.

Current mold problems illustrate that without some thoughtful deliberation, there is unfortunately a significant risk of making unconscious compromises which result in mold-fragile buildings.

In other cases the suggestions do indeed add cost, or require trade-offs between costs and the reputation of the builder or preferences of the owner, or place new demands on the skills and availability of labor, and or can affect the schedule. Each developer, designer, builder and owner will have to consider these trade-offs and make their decisions accordingly. Nothing is simple in construction. All decisions have consequences, and there are few if any laws to make these particular decisions for us. Everybody must decide how much time, attention and money it's worth to reduce mold risk.

Consider the space shuttle, which completed 100 missions safely before an inherent insulation-moisture-condensation problem resulted in tragic fatalities. In a similar way, it's possible to build hundreds of homes using the same details without incident... until one day the mixture of time, statistical probability and unconsciously risky practices combines to produce mold. Implementing this three-part strategy provides an effective way to reduce that mold risk.

Three-part strategy

Here's a brief summary of the key aspects of the strategy. In the next section of this guide, we'll provide the details, arranged according to who's likely to be making each decision, and when.

1. Keeping water away

Most moisture gets into a building from water outdoors. There are four components of the annual outdoor water load. From largest and most continuous, to smallest and most intermittent, these are: irrigation, groundwater, rain or snow, and airborne humidity.

Landscaping choices plus the local rainfall dictate the total potential annual amounts of these loads, and also their periodic intensities. But through their early aesthetic and budget choices, the developer, designer, builder and owner will determine ***what percent*** of these potential loads will be safely channelled away from the building, versus the percent of the water load that will actually reach it, challenging the construction.

The actual water load depends on *how much of the rain water* is allowed to flow down the exterior walls, *how much of the surface water* is allowed to accumulate next to and underneath the foundation and *how much of the rain and irrigation spray* will land on the walls. (In California, outdoor humidity is such a small annual load that it does not merit the same attention as the liquid water loads.)

These actual water loads are set for all time, sometimes unconsciously, during the early moments–when the developer decides how far away from the buildings that water will be kept. For example: how close to the lot lines will the homes be built? In which direction will the site drainage slope? Which plants and grasses will be used, and will the roofs overhang the walls?

These earliest decisions, usually made by the developer and the owner, have the most effect on the baseline mold risk.

2. Keeping water out

Every now and then, *some* rain is going to fall on the roof and flow down the exterior wall. And sooner or later *some* irrigation water will land on the walls or form pools at the edge of the house. Plus, groundwater is *always* under the foundation and *some* moisture always gets into materials during construction.

To ensure that such periodic accumulations of moisture don't help grow mold, drain the walls and waterproof the foundation, and don't trap too much moisture in the materials during construction.

Keeping water out of the walls requires three layers of protection, not one. The outer layer–the cladding–stops the bulk of the liquid water. The second layer is an air gap, into which the remaining water can drain when it gets past the outer layer. And the third, innermost layer is a water-resistive barrier, which keeps any water out of the vulnerable sheathing, framing, insulation and interior finish. Given these three layers, the joints and flashing around windows and doors are especially critical and complex assemblies, demanding careful attention from designer and builder.

Waterproofing the foundation requires a capillary break to keep liquid water from seeping into the concrete, and a vapor retarder to keep the water vapor out as well.

These measures are mostly under the control of the designer and the builder. But their cost and effectiveness are heavily influenced by the choices made before and after construction by the developer and by the owner, who determine the net annual water loads on the structure.

3. Limiting mold growth until moisture dries out

Indoors, there will be plumbing leaks, condensation and water spills, sooner or later. To add the third leg to the stool, design and construct the building so that water cannot spread into materials around the source of the leak or spill. Also, make sure the indoor air is dry enough to absorb any occasional moisture. The designer and builder might also consider selecting materials on which mold grows slowly, or not at all—especially for parts of the house which are the most likely to have frequent wetting events, such as the exterior walls and foundation, and the walls of the kitchen, bathrooms and laundry room.

Finally, the owner must contribute to avoiding problems by preventing any water from spreading, and drying it out quickly ensuring that mold can't grow. And it's useful for owners to keep in mind that visible moisture accumulation in walls, ceilings and floors is not normal—when water appears in odd places, let the builder know about the problem so it can be fixed before mold grows.

Section 2

Development

Fig. 2.1 Mold-related development decisions

Mold problems are usually believed to be caused by design and construction defects. But the ***underlying degree of risk*** *is established by the earliest development decisions.*

DEVELOPMENT DECISIONS

In the past, most discussions of mold prevention have focused on details of exterior wall design. Often overlooked in these discussions is the more fundamental role of the initial development decisions, which are based on the developer's perceptions of the needs, wants and budgets of the target customers.

1. Keeping water away

Several developer decisions will either increase or reduce the net moisture load. These decisions determine the building's inherent mold risk and they begin with the land.

Even in southern California, with a dry climate for nearly the entire year, poor decisions about site drainage can be a major source of indoor mold problems. In fact, counter to intuition, there is good evidence that water-related problems have been worse in dry areas than in rainy areas. According to the insurance industry's records, the highest rates for water damage claims come from just 5 of the 16 California climate zones... and all of these high-claim zones are in "dry" southern California.

Site grading, paving, lot coverage and drainage

Rain becomes surface water which flows through the site. The developer decides, through his siting, grading, drainage and other landscaping decisions, whether that surface water will flow towards the buildings or away from them. This decision has enormously good–or bad–consequences.

Keeping water flowing away from buildings automatically reduces the annual moisture load and reduces mold risk. Conversely, allowing water to flow towards the buildings increases the annual load and therefore increases mold risk.

Further, if most of the site is covered by buildings and pavement, rainwater becomes very concentrated. Then the direction of its flow, dictated by gravity and by finish grading, becomes especially important.

Fig. 2.2 Southern California - Dry, but higher mold risk
Against intuition, five of the seven counties in California which have the highest rates for water damage insurance claims are in the "dry" southern part of the state.

Consider, for example, a single family house built on a long, gentle slope, where the access road is above the house. Rainwater will flow down the driveway. If that driveway dead-ends into the house, driveway runoff becomes a periodic challenge to the home's exterior for the life of the building. But if the driveway curves to the side of the house, the building never sees that part of the rainwater load, reducing the risk of mold for the life of the building.

In hillside areas, these water drainage difficulties are multiplied. There is constant economic pressure to build houses closer together, especially in coastal areas where land values are very high.

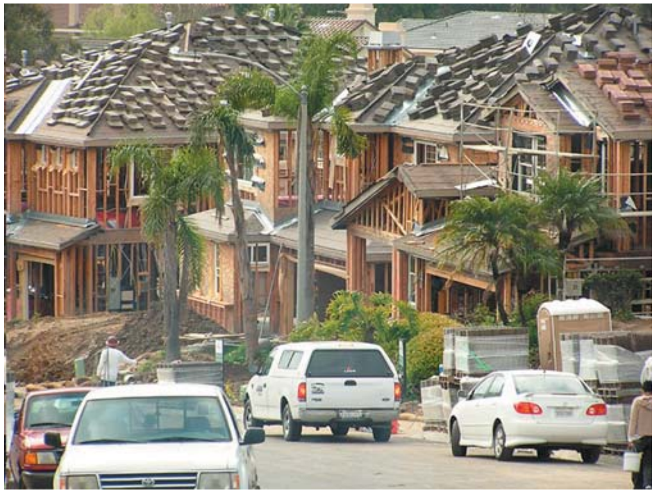


Fig. 2.3 Hillside homes - Site drainage is critical
When houses are built close together on hillsides, rainwater gathers volume and force as it flows down the hill, making the direction and effectiveness of drainage critical in avoiding water intrusion at the base of the downhill buildings.

Rain in dry areas, when it occurs, can be very intense. And this intensity is multiplied many times as rain flows off roofs into narrow spaces between buildings and onto pavements. Keeping it flowing away from buildings greatly reduces mold risk.

Offering xeriscape (dry landscaping)

Xeriscape (dry landscaping) can provide the visual interest and soil stabilization of vegetation, but it relies on plants and grasses which grow well without daily watering. If there's no daily irrigation, then there's less risk that excess moisture will enter though the foundation and less risk from water spraying on the exterior walls through misdirected spray heads.

Providing the buyer with xeriscaping as an alternative to heavily irrigated lawns and bushes has strategic benefits for the developer. From a business risk perspective, it reduces the total number of structures exposed to high daily water loads, reducing the overall risk exposure from mold. From a marketing perspective, xeriscape broadens the appeal of the homes for buyers who may value these benefits more than they value an all-green yard:

- Reducing mold risk
- Conserving water resources
- Minimizing lawn and garden maintenance

Extra care for developments with irrigated landscaping

Two other common features of California developments can multiply the moisture loads on buildings: earth berms for privacy or for decoration, and landscape irrigation.

Berms near buildings often restrict the flow of rainwater, keeping it near foundations, or even forcing it to flow against foundations during storms. Even more importantly, when these berms are built in developments that have daily landscape irrigation, the berms will need excellent drainage to keep all that water away from the foundations. Any climate's *occasional* rain load is far smaller on an annual basis than the water load from *daily* irrigation.

For example, the average annual rainfall in Los Angeles is about 11 inches, and in San Francisco and Sacramento it's about 18 inches per year. Compare that to the 40 to 60 inches a year of irrigation water needed to maintain the color and vigor of grass.

The developer typically defines a set of foundation landscaping options for the owner. These options can include or exclude plants which require daily irrigation.

Near-foundation irrigation has often been a cause of indoor mold. This is not automatically a problem in all cases, but irrigation increases mold risk in three ways. First, the daily presence of water near the foundation increases the chances that some of the water will find its way into the building through cracks between the slab and the exterior walls, and by capillary suction through the edge of the slab itself and into the flooring adhesive. Second, any broken spray heads can place massive amounts of unwanted water near the foundation every day. Third, if the wrong spray head is installed on the riser or its spray arc is misaligned, the system may be spraying water upwards against walls and windows. Walls and windows can often be quite vulnerable to this large, daily, upwardly-directed spray load.

Just as importantly, plantings near the foundation can block the free drainage of surface and rain water. The finish grading should always include a slight slope away from the building.

But plantings are sometimes level-graded, or have decorative borders (sometimes called the "Landscaper's Moat" by mold investigators) which prevent rainwater from draining freely away from the building.

So if daily watering near the foundation is the plan, the designer should take steps to reduce that life-of-the-house risk through other means, such as more elaborate measures to ensure foundation waterproofing.

Fig. 2.4
Roof overhangs - Longer is better
Note how even a short overhang greatly reduces the water load on the wall below. Such simple, time-proven architectural features can reduce the net annual water load—therefore the volume of rain leaks around windows—by more than 50%

Zero setback lot-lines increase risk

To maximize profit and minimize costs, it's economically difficult if not impractical to resist the practice of building the house all the way to the edge of the next lot, where allowed by zoning laws. While the wisdom of such laws might be questionable from a public policy and building science perspective, they probably reduce the cost of houses on a square foot basis, because they reduce the cost of land. But it's useful to keep in mind that building on the lot line makes it easy for an owner to hugely increase mold risk for his neighbor.

For example, knee-high irrigated planter boxes have been built by some owners right onto the walls of their neighbors' homes, without ensuring that the back of the box (and therefore the neighbors wall) is watertight. Also, spray irrigation from one owner's green lawn has the potential to soak-down the exterior wall of his neighbor's home every day, leading to major problems from any hole or crack or unsealed joint in that wall. Compounding the problem, privacy fences are common on such small lots. So the affected neighbor might learn about these poor practices only after mold begins to grow inside his home.

Unless the developer puts clear language in the homeowners contract to prevent such problems, the developer may be at risk for mold problems which result from one owner adding water to another's structure.

Also, the developer's guidelines to the designer should be clear on the matter of drainage between lots. If the finish grading of each lot virtually guarantees that any water from one lot will collect near the foundation of another building, the developer may be at risk for any mold problems that result.

So when planning a development with zero setbacks from lot lines, it might be prudent to reduce the risk of this practice by:

- Ensuring clear contract language prohibiting one neighbor from wetting any of his neighbors' buildings.
- Instructing the designer to provide especially robust water-exclusion measures as suggested in the design section, plus excellent foundation drainage for any exterior walls that extend all the way to the lot line.
- Providing the designer and builder with budgets large enough to accommodate these measures.

2. Keeping water out

In the development phase, some budget-related decisions may affect the building's ability to drain and dry quickly. Specifically, the designer and builder will need ***budgets*** for components and assemblies which minimize the loads and let wet assemblies dry.

These items are usually included in baseline budgets for most modern developments. But, if such items are eliminated by the developer's budget concerns, the risk of mold increases.

Roof line decisions which favor water-exclusion

When rain flows down the outside of the building, it will seep into any cracks in the construction. So if less water flows down the building, there is less risk of mold from water leaks through cracks.

Roof overhangs greatly reduce the volume of water which flows down the side of the building. In climates with infrequent short bursts of intense rainfall, as in Southern California, a two-foot roof overhang cuts the annual water flow down the building walls (and therefore into cracks) by more than 50%.

Roof overhangs and their dimensions, or the lack of overhangs entirely, are aesthetic and economic decisions usually made by the developer on behalf of the owner. If the building has generous roof overhangs, the mold risk is reduced. Another benefit of generous overhangs is a smaller annual cooling load, which reduces utility bills.

Progress payments that favor watertight connections

It's not obvious how financing decisions can lead to mold. But one very common water intrusion problem can sometimes be influenced by the structure and timing of progress payments to the builder.

One of the places that water enters a building is around windows. Flashing, which forces the water back out of the building, must be integrated into the water-resistive barrier–the relatively impermeable membrane which excludes water. The WRB must be laid *on top* of the flashing at the top, and *under* the flashing at the bottom of those windows. Otherwise, the inevitable leaks will result in water intrusion into the exterior wall, which eventually leads to mold. According to the actual records of one builder, costs associated with *fixing* just one leak might be as low as $200, but can increase to $15,000 at the stage when mold must be remediated.

Problems arise when construction financing is arranged so the builder receives a significant cash payment after the windows are installed in the wall. This creates a perverse incentive: install the windows as soon as possible, even if only the framing is complete.

This mold risk can be reduced when the builder's incentives favor water-tight connections instead of discouraging them. For example, consider arranging progress payments so the builder receives a major infusion of cash not after just the windows are installed, but rather after the entire assembly is complete. That is to say after the sheathing,

Fig. 2.5
Progess payments can influence mold risk for better—or for worse
These windows were installed without flashing, and before the water-resistive barrier. So when they eventually leak, water will go directly into the walls. If the builder's progress payment depended on a watertight connection instead of "getting the windows in," mold risk would be reduced.

sill flashing and water-resistive barrier (WRB) are installed and the windows, door frames and head flashing are tied into them to form a watertight assembly.

Beyond developers, mortgage bankers and insurance providers can also reflect on the fact that *their* risks are reduced when progress payments encourage watertight connections. When their financing and insurance requirements encourage watertight assemblies, these industries can be a powerful force for positive change with respect to reducing mold risk.

Below-grade walls on hillsides have greater risks for mold

When considered as an annual average, the outdoor air is quite dry in most of California. The earth, however, retains moisture for most of the year in nearly all locations. So when exterior walls are built into a hillside, the developer should be aware that the risk of excess moisture in those walls is high.

Of course, houses built with hillside walls are quite common. And in other parts of the US, entire finished basements below grade are the norm.

On the other hand, the developer can reduce risk by understanding that, when hillside walls are necessary, the designer needs enough money in the budget to take the same precautions that are often taken for finished basements below grade.

These precautions are discussed in more depth in the designers' section of this report. But they include extra attention to lot drainage between buildings, waterproofing with a drainage mat and foundation drain on the outside of the wall, and moisture-tolerant materials and finishes for the indoor face of a hillside wall.

3. Limiting mold growth

As with draining and drying, developers' budget decisions can affect the building's ability to limit mold growth. The designer and builder can reduce mold risk if they have budgets for:

- Sheathing panels intended for exterior use rather than for interior finish. These are more durable with respect to moisture problems, but not all codes insist on robust sheathing.
- Tub/showerwall panels designed for periodic wet exposure instead of for standard interior finish.

Again, most developers understand the importance of these items. But if these are eliminated by later budget concerns, the risk of mold increases.

Fig. 2.6 Budget decisions establish the baseline mold risk

This building is being sheathed with interior-grade, paper-faced gypsum board. While still excellent for fire protection, paper-faced material without fungicide or moisture protection is much more mold-risky than exterior gypsum, or wood or cement-based sheathing, especially for the exterior wall, where some leaks are inevitable. The developer controls this mold risk through budget decisions. (In contrast, the safety violations shown in this photo are under the control of the builder!)

Section 3

Design

Fig. 3.1 Architectural Design

After the developer has established the baseline mold risk, the architectural designer can reduce (or increase) that risk for the builder and owner.

DESIGN DECISIONS

After the budgets and infrastructure decisions are complete, the designer takes charge, deciding how to exclude the net water loads which result from the development decisions.

Most of the suggestions included in this section are simply good practice. Very few are required by law. With little legal compulsion at the design phase (but catastrophic legal consequences which follow a mold event) the designer is often faced with trade-offs between the delightful visible features that sell houses vs. hidden features that keep them robust and free from mold.

On the other hand, the designer does not always have to choose one or the other. In fact, the most important choices the designer can make are the first design decisions: those which either keep water away from the house, or which bring more water (and therefore more risk) towards the house.

1. Keeping water away

Architectural look-and-feel decisions which keep water away

If the water-critical aesthetic decisions have not already been made by the developer, the designer will make them. In those few moments, it will be the designer who decides *how much* of the annual weather moisture load will be allowed to reach the edge of the building. As described earlier, these decisions include:

- Keeping surface water from reaching the foundation by site grading and by excellent drainage.
- Keeping irrigation and earth berms away from the foundation to avoid daily puddles near the building.
- Deciding to overhang the roof so that only a small fraction of the annual rainfall can possibly flow down the side of the building.

These decisions are the first and most important ones, because they will decide the *dimension of the risk of all other design and construction decisions*. Larger loads produce larger risks. Through these decisions, the designer can cut the moisture loads to nearly inconsequential amounts in dry climates, and very low amounts even in very rainy climates.

Conversely, if the designer decides to ignore the impact of site drainage and roof overhangs, every design detail, every craftsman's skill level, every construction sequencing decision, and every material selection becomes more costly, challenging and risky.

Fig. 3.2 Roof overhangs reduce risk
Wide overhangs keep rainwater off the wall, so much less water flows down over windows—the most common locations for rain leaks. Without such overhangs, the annual water load increases by more than 50%.

Fireproof roof overhangs for urban-wildlife interface zones

There is one competing concern with respect to roof overhangs. In urban-wildlife interface zones, forest wildfire can threaten houses. In those areas, roof overhangs should be made fire-resistant. Otherwise the exposed edges could catch fire.

Fire-retardant construction of roof overhangs simply means using non-combustible material for the underside of the overhang (the soffit), and venting the roof not as usual from the soffit, but rather from the shingled side of the roof, through fire-resistant roof vents, or using designs which eliminate roof venting altogether.

Xeriscape reduces annual water loads and risks

When chosen by the developer and/or owner, xeriscape (dry landscaping) is an excellent way to reduce the annual water load on the home, and therefore reduce the risk of mold.

More than half of the water consumed by homeowners in California is used for irrigation. Daily irrigation uses tens of thousands of gallons of water per year per home—about 4 to 6 times greater than the annual average rain load in California (9 to 20 inches of rain per year vs. 40 to 60 inches per year for irrigation). Any reduction in irrigation load reduces the risk that some of that water will get into the house.

Xeriscape provides the visual interest and soil stabilization of vegetation, but uses xerophilic (dry-loving) plants and grasses to achieve these benefits. From the designer's perspective, it's important to ensure that:

- Any existing lawn grass is entirely removed
- The vertical soil profile can support the plants. They'll need topsoil that is fertile, weed-free and firm but uncompacted. That layer sits on compacted subsoil, with a smooth-locking interface between the two.
- In addition to visual effects, plants are grouped around the site consistent with their respective needs for water, light, soil and shade.
- Plants are selected with enough diversity to provide color and visual interest throughout the year.
- The plants selected are numerous enough and have a root structure robust enough to provide erosion control, particularly on steep slopes.

For more comprehensive guidance about xeriscape, the designer can consult the well-written and illustrated color manual produced by the US Department of Agriculture, titled: " Creating Native Landscapes for the Northern Great Plains and Rocky Mountains." The publication is available online at:

http://www.mt.nrcs.usda.gov/technical/ecs/plants/xeriscp/

And for an understanding of plants that have historically thrived in different parts of California without irrigation, the designer can consult the website of the California Natural Plant Society (www.cnps.org). The society maintains a geographically-divided, searchable database at:

http://davisherb.ucdavis.edu/cnpsActiveServer/index.html

Houses with zero setback lot lines require extra attention

When the building extends all the way to the lot line, the designer's task is complicated by the fact that homeowners can unwittingly create mold problems for their neighbors. For example, when one neighbor changes the grading in his yard, or adds irrigation, or builds decorative planters against his neighbor's home, he might be adding a daily water load to that other building.

There is only so much the designer can do to protect one home owner from risky decisions made by another. But when the developer decides to build all the way to the lot line, the designer should be aware of the increased risk, and consider taking such measures as:

- Waterproofing the lower part of the sheathing of the lot-line wall with mastic.
- Using cement board as the exterior sheathing for the bottom few feet of the wall.
- Specifying plastic composite or pressure-treated lumber for the sill plate of the wall.
- Setting the entire lot-line wall into a sill in the foundation slab.

- Bringing the foundation concrete up to form a stub wall one foot above grade, and waterproofing the exterior of that stub wall to help protect against future grade changes by neighbors.
- Specifying fiberglass-faced gypsum board or similar water-resistant material for the interior finish of that exterior wall on the lot line.

2. Keeping water out

Minimize the number of roof valleys & dormers

The valley of a roof is where rainwater becomes concentrated–creating a far larger water loading per square inch than on the roof surface itself. It's also where different pieces of roofing and flashing come together.

Consequently, in a rainstorm, the valleys combine the highest possible water load with highly vulnerable construction joints–creating a very high-risk zone for moisture intrusion.

Roof-dormer connections are similarly risky. The joints between the roof and the many sides of dormers also see fairly high water concentrations, and there are many joints in these connections.

Fig. 3.3 Kickout flashing is essential
Without kickout flashing, water can easily get into a wall clad in stucco or clad in EIFS (Exterior Insulation and Finish System).

Kickout Flashing, which keeps water out of the vertical adjoining wall

Without this kickout, water would have been able to get behind the stucco, growing mold on the sheathing below this joint.

Fig. 3.4 Each roof-wall or balcony connection increases mold risk
The more complex the roof, the greater is the probability that one or more connections will leak. Current design aesthetics favor complex roofs—but they're risky.

On one hand, these potential problems are well known among designers, contractors and roofers. So one would hope that everybody will be giving the valleys and dormers more-than-usual attention. On the other hand, current aesthetics strongly favor highly complex roofs with many valleys and dormers, increasing the probability that one or more of these many joints will leak water at some time in the life of the home.

The designer (and the owner) might want to reflect on the inevitability of water leakage in some percentage of these joints. The more such joints exist in a single house, the more risk exists of a water leak in that house.

This is not to suggest that the designer should not include valleys and dormers. But to paraphrase Dirty Harry: "How lucky do you feel today...?" It's useful for both designer and owner to realize that these are inherently risky design features, and that no roofing crew is perfect all the time.

Kickout flashing wherever a sloping roof ends at a vertical wall

Many of the well-publicized mold events caused by "stucco problems" occur where a sloping roof ends at a vertical wall–one which does not end at the roof edge. An example is shown in figure 3.4.

When rainwater runs down the roof, step flashing prevents it from leaking into the adjoining vertical wall... until the water stream reaches the edge of the roof. At that point, it gets very tricky to make sure that all the water goes over the roof edge, instead of leaking into the vertical wall through the complex joint between roof, siding and flashing.

To avoid this leakage, design the joint with "kickout" flashing at the edge of the roof. As shown in figure 3.3, this small piece of flashing scoops the water away from the wall and guides it out over the edge of the roof, preventing it from getting down into the wall below the joint. The flashing "kicks out" the downward-flowing water stream.

The key to success of this detail, of course, is that there be no leak in the corner of the kickout flashing itself. It must either be a continuous piece of formed plastic, or a soldered metal fabrication. A spot-welded or riveted connection is simply not going to stay watertight for the life of the building after the sealant ages and fails.

Keep liquid water and vapor out of concrete slab foundations

One of the oddest aspects of mold growth in California housing has been the frequency of problems with concrete slab floors in near-desert climates. Given that excess moisture is necessary for mold growth, how could such problems occur near such a basically dry, mold-tolerant material like concrete, located in very dry parts of the state?

Unlike many other mold-risk decisions, current law ***does*** influence the designer's and builder's actions with respect to foundations.

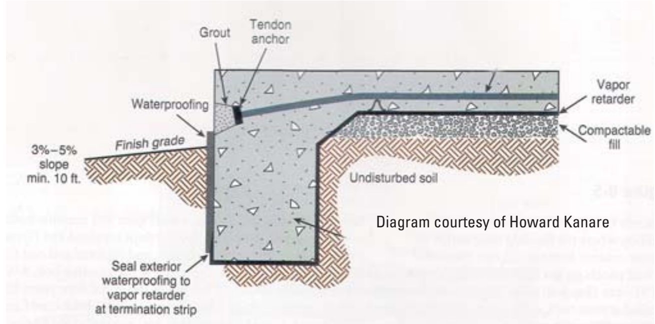


Fig. 3.5 Vapor retarder below the slab—not below the stone

Recent guidance from the American Concrete Institute (ACI 302.1R-04)[1] *argues in favor of placing a continuous vapor retarder in contact with the slab, not under the stone.*[2]

California Senate Bill 800, signed into law in September 2002, defined several actionable construction defects. The bill required that, among other things: "...the foundation or foundation slab shall not allow water or water vapor to enter the structure so as to cause damage to another building component." Further, "...the foundation or foundation slab shall not allow water or water vapor to enter the structure so as to limit the installation of the type of flooring materials typically used for the particular application."

So both designers and builders would be wise to give especially careful attention to foundation drainage and to capillary breaks. California law requires the builder to provide dry foundations to avoid exposure to construction defect lawsuits.

Usually, mold problems have happened when building code interpretations and building practices have combined to create large water reservoirs immediately underneath the concrete. Then, water in that reservoir diffuses upward through the slab, adding enough moisture to the flooring adhesive and the flooring itself to create flooring failure and to sustain mold growth.

These water reservoirs are created when workers start with a sheet of vapor retarder material, then add a layer of sand or fine

Fig. 3.6
Capillary break under the foundation
Placing crushed stone under the foundation makes it less likely for water to wick upwards and diffuse through the vapor barrier to grow mold under flooring.

aggregate on top of it. That layer provides the base for pouring the concrete slab. But often the support layer stays saturated with water, because the vapor retarder below that material prevents water from draining away safely. Excess water in the support layer comes from many sources:

- Rain which falls before the concrete is poured.
- The necessary excess water in the concrete mix (about 45 gallons per cubic yard), without which the mixture would be too stiff to pour.
- Water sprayed on top of the slab to help cure the concrete, and to prevent the slab from drying prematurely, which would result in cracking and spalling.
- Irrigation or landscaping water which pools near the foundation.
- High ground water level in marshy areas or areas subject to snow melt runoff in the spring.

There are two fundamental problems with this design. First, the vapor barrier placed below the aggregate does not allow top-generated water to escape down into the dry earth below the foundation, where it would do no harm. Secondly, the sand actually pulls that top-generated water back upward to the bottom of the slab through capillary suction.

To avoid these problems, use coarse crushed stone rather than sand or fine aggregate (figure 3.6), and place a high-performance vapor retarder between the stone and the concrete slab rather than below the stone (figures 3.5 and 3.7). With this design, groundwater cannot diffuse upward through the concrete for two reasons.

First, the large spaces between the pieces of crushed stone cannot create the necessary capillary suction. Therefore even if the bed of stone were partly filled with water, it could not climb upwards to the bottom of the slab. Secondly, the vapor barrier immediately below the slab prevents any high relative humidity air in the stone bed from diffusing moisture into the concrete.

With this design, recommended by the American Concrete Institute in their *Guide for Concrete Floor & Slab Construction* (ACI 302.1R-04), the building will avoid long-term vapor diffusion and flooring problems. But the builder will have to take short-term measures to prevent problems with curing, spalling and warping immediately after the concrete is poured. These are discussed further in the builder's section of this report.

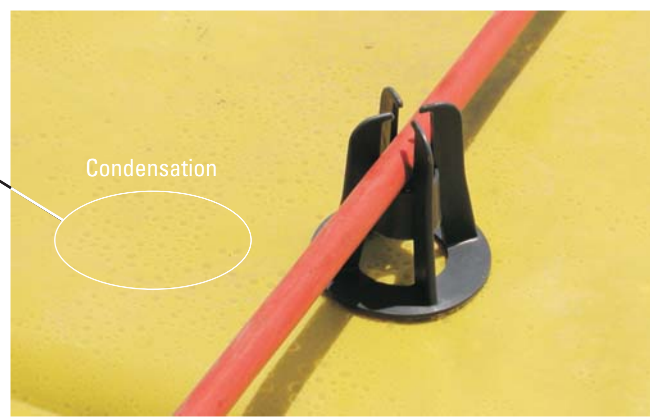


Fig. 3.7 Vapor retarder is essential
Note the condensation which forms under the vapor retarder even in "dry" Southern California. Without the retarder, water diffuses upward to support mold growth in and under flooring.

Perm rating & durability of the foundation vapor retarder

For use under concrete foundations, ASTM defines all three durability classes of vapor retarders as having a maximum perm rating of 0.3. The tougher vapor retarders (classes A and B) are better because they are less likely to be cut or torn during construction, but they cost more. When working with wet soils, the modest cost increase of a lower-perm vapor retarder, which is often more durable as well, can be a cost-effective means of reducing mold risk in flooring.

Grade beams vs. thicker slabs

Population pressure plus earthquakes make soils and civil engineering a bigger part of residential design than in earlier years. As more hillside land, and land with expansive soils or more marshy land and formerly industrial and agricultural lands are being used for building homes, the strength of the foundation, and its ability to exclude ground-based contaminants become even more important than in the past.

One way to design a stronger slab is to pour reinforcing beams (grade beams) through the center of the length and width of the slab in addition to around its perimeter, as shown in figure 3.8. The other way to increase strength is to simply pour a thicker slab.

There are advantages and limitations to each design. Thick slabs take longer to dry after curing, and they use more concrete. With grade beams, the thinner slab can dry more quickly after cure, and it uses less concrete. But from a mold perspective, the more important difference is that, with grade beams, the labor hours and skill needed to properly place, trim and overlap the vapor retarder is rather demanding. And it's impossible to lay an even layer of crushed stone up and down the sides of the trenches that contain the grade beams. So the capillary break is less effective, because it is not continuous.

In contrast, the vapor retarder layers under flat slabs are much easier to place and overlap properly, and therefore are more likely to exclude more water vapor. And placing a uniform layer of crushed stone on top of the vapor retarder as a capillary break is fairly easy on a basically flat surface, reducing the potential for bulk water leaking through the overlapped seams.

Fig. 3.8 Installing the vapor retarder and capillary break layer is difficult under slabs with grade beams
Placing and overlapping the plastic evenly up and down the trenches that form the grade beams is difficult. Designing thicker flat slabs without grade beams is less subject to installation error, and may save overall costs because of the reduced labor.

Both grade beams and thick slabs can work. Flat slabs probably make it easier and less costly to keep water out, and therefore probably reduce mold risk. But your soil/civil engineer will be your best advisor for optimal foundation design for the specific site you have in mind.

Consolidated guidance on concrete floors & moisture

Balancing all these factors is a challenge. The Portland Cement Association provides excellent advice through its recent book: *Concrete Floors and Moisture*, by Howard Kanare. (2005, Portland Cement Association, Skokie, Il, (847) 966-6200, www.cement.org) The book includes the background of the decades-long discussions and trade-offs which resulted in the current ACI 302.1. Its clearly-written text and color graphics guide both the designer and builder through the multitude of decisions and the sequencing which helps ensure foundations neither leak water nor allow water vapor into flooring.

Crawl spaces need sealed, vapor-retarding ground covers

Mold growing on framing and flooring above crawl spaces is a common problem in all parts of North America. In crawl space houses, 40 to 60% of the indoor air comes from leakage pulled by the stack effect from that crawl space. Such upward air leakage brings any mold spores or odors from the crawl space into the occupant's breathing zone.

To prevent mold growth in framing and flooring above the crawl space, block the slow but continuous evaporation from the earth under the home. If the designer specifies an overlapped and tape-sealed vapor retarder on top of that earth, the vapor load is almost entirely eliminated.

That barrier must be continuous. In other words, the sheets must overlap, and be trimmed snugly around any penetrations such as support piers and plumbing connections. This is not simple. The designer can specify this, but it's not likely to happen unless the builder has a subcontractor experienced in the art. The manufacturer of the vapor barrier material can be an excellent source of referrals to capable contractors.

An alternative is a thin, non-structural layer of concrete, coated with a liquid-applied vapor barrier such as epoxy paint. In homes with many floor support piers and plumbing connections, concrete may be easier to place and less expensive to make vapor-tight than cutting and placing heavy plastic sheets, and then overlapping all the seams and trimming closely around all penetrations.

Fig. 3.9 Two layers under stucco
Stucco will adhere tightly to the first layer it contacts. So you must have a second, water-resistive layer to ensure an air gap behind the stucco for drainage, and to provide water protection for the sheathing.

Further, after years of controversy, building scientists largely agree that crawl spaces should never be vented, in any climate, at any time of the year. The better plan is to make them water- and vapor-tight, just as a basement must be. This guidance provides three benefits: mold prevention, structural durability and fire protection in urban-wildlife interface areas. When the crawl space is made dry, there are no good reasons for venting it. And unfortunately, venting a crawl space built on moist earth does not keep it dry enough to prevent problems.

Two layers of building paper or housewrap between stucco & sheathing

One of the virtues of cement stucco is that it is very moisture-tolerant, absorbing and releasing moisture hundreds of thousands of times without damage or mold growth. Part of the reason it tolerates moisture is because it allows water movement through it. At the same time, however, this means that during a rainstorm, at least some water will pass through the stucco.

So behind stucco, as with any other wall, there should be a small air gap for drainage, followed by a water-resistive layer to protect the sheathing behind the air gap.

The problem arises when the stucco bridges that air gap by adhering to the housewrap or building paper which protects the sheathing. Without the air gap, moisture cannot drain freely downwards, so the moist stucco/building paper composite layer stays in contact with the sheathing. Over time, that moisture breaches the paper and soaks the sheathing, leading to mold.

The solution, now outlined in the International Residential Code, is simply to use *two layers of housewrap or building paper behind all stucco*.[3] The outer layer will adhere to the stucco. But there will always be a small air gap between the outer and inner sheets. That air gap will be sufficient to keep the stucco out of direct contact with the sheathing, and will allow water to drain down between the two layers of housewrap or building paper.

The outer layer in contact with the stucco does not need to be especially durable or costly. Its principal purpose is short-lived. During application, it creates that small drainage gap by keeping the stucco from adhering to the inner layer.

But it's quite important that the inner layer be durable. For the life of the building, that inner layer will have to act as the impermeable drainage plane and protect the sheathing from moisture.

Expansion cracks between stucco and window frames

Joints between stucco and window frames frequently leak water. The problem results from the fact that vinyl expands and contracts with temperature changes much more than does cement stucco. Compounding the problem, this expansion and contraction happens every day because of day-night temperature changes. In fact, vinyl expands and contracts even more than aluminum, but both types of frames have had similar problems where the frames meet the stucco. Sealants alone have not been effective against this expansion and contraction.

So anywhere that stucco meets a window or door frame, expect a crack. To limit water intrusion around frames:

- Design roof overhangs to reduce the volume of water that will be flowing down the wall into those cracks.
- Ensure that windows and doors are flashed on top, on the sides and on the sills, so that the water that *does* get in, will be forced right *back out* again. The guidance provided by ASTM Standard E2112 is very useful for this point, especially if the manufacturer does not provide enough detail to be certain of a good result.
- When the window manufacturer's instructions call for sealant, make sure the material is applied in the manner and in *exactly the locations shown in those instructions and not others*, avoiding the potential for trapping moisture instead of excluding it.

No impermeable paint over stucco

Stucco freely absorbs and releases water rather than trapping it. So the designer must be careful not to defeat this virtuous property by covering the stucco with impermeable paint.

This is not intuitive. Many assume that, to protect the building from moisture damage, it would be best to put impermeable paint on the outside of the building–on the stucco. Unfortunately, that logic has not worked out well in the field, and the "stucco problems" it causes have become notorious.

The problem is that some water will still get in, but an impermeable paint layer will keep the water from *getting back out*. Then over time, small amounts of water will accumulate and lead to both mold and further cracks, which let in more water. If stucco is deprived of its ability to release moisture, a small water problem under that stucco quickly becomes a very big mold problem. Often, parts of the entire exterior wall must be rebuilt, sometimes including new framing.

The solution is for the designer to specify that any paint or other coating must have a permeability rating of at least 10 perm if it is to be used on exterior stucco. That simple specification (if followed by the builder and owner) will let the stucco dry out after getting wet, and help avoid mold problems.

Avoiding classic stucco problems in general

Beyond the key points made here, the reader may be interested to learn more about the behavior of stucco with respect to water intrusion. Two references are helpful to the designer who seeks to avoid known problems through better details:

- "A Close Look at Stucco" Dennis McCoy. *Journal of Light Construction*, September, 2003
- "Why Stucco Walls Got Wet; Lessons from Florida Hurricanes." Joe Lstiburek, *Journal of Light Construction*. July 2005

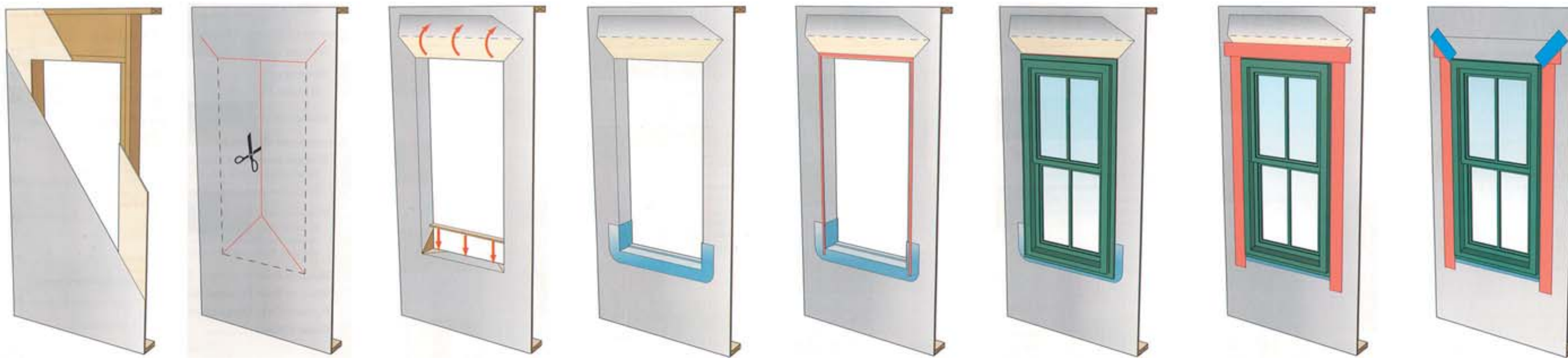


Illustration courtesy of Joseph Lstiburek, PhD.

Step 1
Wood frame wall with OSB and housewrap

Step 2
Cut modified "I" in housewrap

Step 3
Fold housewrap in at jambs and sill. Fold up at head, temporarily. Install backdam of sill pan.

Step 4
Install formable flashing over the sill and backdam per manufacturers instructions

Step 5
Apply sealant at jambs and head. Sealants, housewrap and flashings must be chemically compatible.

Step 6
Install window plumb, level, square and fully-supported per manufacturers instructions

Step 7
Install jamb flashing and head flashing

Step 8
Fold down housewrap at head. Tape head flashing. Air-seal window around entire perimeter on the interior, with sealant or non-expanding foam.

Fig. 3.10
Flashing and sill pan sequence diagram showing all layers

This diagram, from the Water Management Guide[4] published by Building Science Press, shows workers exactly which steps are needed, and in what sequence, to provide water-tight constuction. Similar diagrams for 17 other types of walls are contained in that reference book.

Note that this particular design calls for some type of self-adhered flashing. Designers should be aware that the performance and specifications for these products, previously somewhat less formalized, are now defined by the AAMA's voluntary specification #711-05.

Integrating window flashing & sill pans with the water-resistive barrier

Dr. Joe Lstiburek, the noted building scientist, has said that in his 30 years of consulting and building experience, he has observed that "there only two kinds of windows: windows that leak now... and those that will leak later."

The designer can minimize the mold risk from window leaks in two important ways. First, reduce the volume of water likely to flow through those leaks by providing generous roof overhangs. That way, not much water ever challenges the window joints. Any small amount of water is likely to dry out before it causes a problem.

Secondly, the designer can design and clearly draw the integration between the four key elements that must all work as a system to exclude water: the window, the sill pan, the flashing and the water-resistive barrier.

That second item is easy to say but very tough to do. The variety of window designs, combined with the variety of wall designs, ensures that integrating them to exclude water will be complex, which means it will be difficult to accomplish under field conditions. That's why it is so important to minimize the water load by providing generous roof overhangs. When the water load is low, any shortcoming of the joinery between flashing, sill pan, water-resistive barrier and window is less likely to result in mold.

ASTM Standard E2112[5] is the best generic guide for this always-complex integration. At 125 pages (and growing), its title is "Standard Practice for the Installation of Exterior Windows, Doors and Skylights." But equally important are the instructions provided by the manufacturer of the windows you choose to specify. Similar-looking windows from different manufacturers are seldom intended to be installed and integrated into the other elements in *exactly* the same way. So while ASTM E2112 provides the basic principles, the critical integration details will always be specific to a given model of window and a given wall design. "Or Equal" field substitutions have often been the source of problems in integration, which means they increase the risk of water penetration and mold.

Two aspects of window integration that have historically been weak in design documents are sill pans and flashing details.

Sill pan flashing, shown in figures 3.10 and 3.11, ensures that water getting through the window joints will be forced outwards to the drainage plane, where it can do no harm, instead of draining downwards into the wall, where the water would collect and eventually support mold growth on sheathing, insulation, framing and wallboard.

Sill pan flashing is simple in principle. First, make sure the bottom of the pan slopes outward just a bit, and that its outer lip extends out and over the edge of the window frame and over the water-resistive barrier. Then, be sure that each end of the pan and its back edge have water-tight lips ("end dams" and a "back dam") to keep water from leaking out the corners and seams of the pan. Of course, when the pan flashing is constructed from separate pieces, as is common, make sure that all the pieces are sealed together with overlaps and durable, water-tight sealants.

In practice, it is not quite so simple to install pan flashing with water-tight end dams and back dams. And any leakage can be a big problem in a short time, especially in buildings without roof overhangs. In the past, the responsibility for flashing windows has not been well-defined. The designer, the general contractor, the framing crew, the window manufacturer and the siding crew are all responsible for pieces–therefore it's easy for any problem to be blamed on somebody else.

But increasingly, the designer is being tagged with the responsibility for detailing the window flashing, and "Install per window manufacturer's instructions" is not always considered an adequate discharge of the designer's responsibility.

Especially in cases where the builder acts as the designer, it has become important to specify exactly which crew has responsibility for installing the pan flashing and connecting it to the water-resistive barrier. It's equally important to provide working drawings that the crew can actually understand (in the heat, in a different language, at the end of a long day, when the project manager might not be on-site to answer questions).

3-D drawings, in a series which shows each installation step, are by far the best way to communicate how the pan flashing should be constructed and connected to the water-resistive barrier. The illustrations in figure 3.10 show an example of such 3-D sequence-diagrams for pan-flashing a window inserted into a wood frame wall with foam sheathing.

This figure comes from the *Water Management Guide*, published jointly by the Energy & Environmental Building Association and Building Science Press.[3] That publication contains similar details for a wide variety of wall construction types, from stucco to brick to masonry block and clapboards. The designer can use that publication as a guide for drawing the sequence diagrams that will be so useful to include in the construction documents.

The importance of air seals under windows

The back dam and end dams of the sill pan are obviously critical components. They keep any leakage water from dripping into the wall at the edges of the sill. But sometimes overlooked is the importance of the *air seal between the bottom of the window and the sill pan*. Window manufacturers' testing has consistently shown that

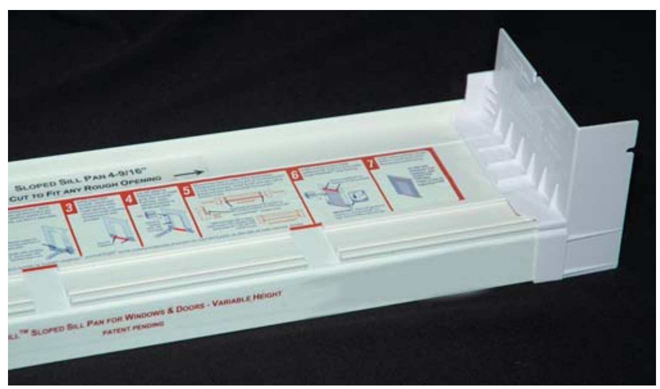


Photo courtesy of SureSill, Ltd.

Fig. 3.11
Preformed sill pan with end dams and back dam
Sill pans can be prefabricated, as in this example, or formed in-place using peel-and-stick membranes. In both cases, it's very important for the designer to define, in 3 dimensions, exactly how the other flashings and water-resistive layers are supposed to connect with, or be placed under or over, the surfaces of the sill pans.

Fig. 3.12
Air seals help exclude wind-riven water
Sealing the air space between the window and the sill pan keeps wind from flowing through and pushing rain or leakage water inwards–up and over the edge of the sill pan and into the wall. Foam sealants are quite effective in this role, provided the foam is chemically compatible with both the sill pan materials and the frame of the window.

by sealing the space between the pan and the window with foam, the water exclusion performance of the system improves. When the wind can't blow through that slot, it can't drive water inwards over the back dam and into the wall.

Plus, there's an obvious energy benefit to keeping hot and cold winds from blowing into the home through all those slots all year long, even when it's not raining.

Below-grade exterior walls on hillsides

The moisture contained in the earth provides a constant risk of excess moisture in exterior walls that are set into the hillside. These walls need the same water-protection measures used for basement walls in cold climates. Specifically:

- Grade the lots in a way that ensures that rain or irrigation water from one lot cannot flow down and collect against the below-grade walls of another home lower on the hill.
- Waterproof the exterior of any wall which is covered by earth on the outside.
- Provide coarse aggregate or drainage matting against the entire exterior of the wall to relieve any hydrostatic pressure, and also provide a horizontal drain at the foot of the wall to ensure that the matting on the vertical surface does not fill up with water. Both of these will also need fabric filters to exclude fine dirt, so that the drainage components do not clog over time.
- Specify moisture-resistant materials for the indoor side of that exterior wall. For example, consider specifying mold-resistant gypsum wall board, treated lumber and composite trim. And avoid moisture-sensitive materials like untreated paper-based products, untreated oriented strand board (OSB) or "hard board" near those walls.

3. Limiting mold growth

A recent study by the Chubb Insurance Companies randomly surveyed 1,663 homeowners all across the U.S. Interestingly, 31 percent of these homeowners had–at some point in their lives as homeowners–experienced water damage problems resulting from roof leaks. And 20 percent of respondents had water damage from plumbing leaks or from burst water pipes.

Based on those results, a designer can reasonably assume that sooner or later many of his buildings will have a significant water damage event, in addition to the smaller, chronic water intrusion problems typical of nearly all housing. So here are some suggestions for shortening drying times, avoiding trapped moisture inside walls and for choosing materials which resist mold growth while moisture is drying out.

Breathable interior finish

When water gets into the exterior wall, it's supposed to be forced back outdoors by the flashing. But often, the flashing is imperfect-especially in the corners. And occasionally there are plumbing leaks and condensation problems. Further, in California most of the wood framing is not kiln-dried before installation. The idea is that, in the dry California climate, the framing members will dry out over time. But this means that the walls must allow the excess moisture from the green wood to dry out, rather than become trapped and support mold.

Glossy enamel interior paint and vinyl wall coverings have often been responsible for trapping moisture inside walls. Avoiding these less permeable interior finishes helps reduce the risk of moisture problems from green lumber and from minor moisture accumulations. With relatively permeable wall finishes (10 perm or above), small amounts of moisture will dry out as the water evaporates and the vapor slowly diffuses through the wall to the drier environment of the air conditioned space.

Somewhat counter-intuitively, when walls are built with steel studs, it's even more important to avoid impermeable finishes. Thin steel does not tolerate moisture well; it rusts away quickly.

It is true that, with steel studs, there is no "green lumber" to dry out–so with steel there may be less mold risk during the first year of the building's life. But later, wood gains a big advantage over steel. After that first year any initial excess moisture in wood is usually gone. For the rest of the building's life, the wood becomes an excellent storage buffer for small amounts of intermittent leakage or condensation.

When small amounts of leaking water reach wood, they are absorbed, keeping that water from migrating into more sensitive materials nearby, such as gypsum wall board or carpets. Then the wood can slowly redistribute and release that water through evaporation–provided that the process is not blocked by impermeable finishes.

Even in California, where building with relatively wet wood has been common practice, framing lumber usually dries down to 8 to 10% moisture content after the first year.

Using the USDA 15% average moisture content limit (with 19% as a maximum reading in that average)[6], dried lumber near a water leak can later re-absorb a substantial fraction of its weight before there is significant risk of mold growth in the wood. Dried wood framing provides a superb, low-cost reservoir for occasional small spills, leaks or condensation—as long as any evaporating moisture is not trapped inside the wall by the interior finish.

With wood, the designer must remain keenly aware of problems that can come from assuming that framing lumber will be "dry enough" when it is installed. Sometimes wood may be much wetter than 15% average moisture content. This is often true in California, where "partially-air-dried" lumber has sometimes been considered acceptable, perhaps based on the assumption that in the dry climate the wood will dry down to safe levels before mold can grow.

This traditional assumption is not always valid with current building practices. Average wood moisture content of partly-air-dried lumber may initially be much higher than 15% if it's been left out in the rain. Further, buildings are no longer allowed to leak air as freely as in the past, so any wet framing will take longer to dry.

While the wood itself may not grow much mold, overly wet framing has often been responsible for very costly mold problems. Wet wood can transfer its moisture to nearby gypsum wall board as it dries, leading to mold growth on the wall board. The implication for the designer is clear: Don't allow interior paints and wall coverings which trap moisture from damp framing lumber in the wall. Specify finishes that pass vapor at a rate of at least 10 perm—and much higher perm ratings can further reduce risk.

Permeable interior finish is even more important when the *exterior* cladding system is *not* permeable, as in the case of external insulation & finish systems, sometimes called EIFS or synthetic stucco. With EIFS, water in the exterior walls cannot easily escape to the outdoors via diffusion and evaporation. So it's extraordinarily important to allow any trapped water to evaporate and diffuse *inward* through permeable interior finishes.

The most notorious mold and structural failure problems associated with EIFS have occurred when water leaks were trapped between the EIFS on the outside and vinyl wall covering on the inside. The trapped water feeds mold growth, rots wood and corrodes steel studs, leading to spectacularly expensive problems and lengthy lawsuits.

So regardless of the builder's preference for framing or for exterior cladding, it's best to make sure the interior finish of all exterior walls can pass water vapor freely. That way moisture won't become trapped inside those walls to cause problems.

Vapor barriers... Location, location, location

Nationally, the advice from building scientists on vapor barriers is not quite as simple and clear-cut as their advice recommending breathable interior finishes.

To begin with, even the name has become complicated. Building material suppliers have adopted the more technically accurate term "vapor retarder" for most materials. The word "retarder" makes for clumsy speech, but it accurately describes the fact that most films have some degree of vapor permeability. There is some agreement that the term "vapor barrier" can and should still be applied to films with very low permeance (less than 0.1 perm). Otherwise, for most materials the term "vapor retarder" is now more common.

Not only is the terminology more complex these days, but the opinions of different experts from different parts of the world have been contradictory–which tells you right away that experience with vapor retarders has varied considerably with geography. Current building codes throughout the USA still reflect this confusion. But recently, most experts have reached agreement on recommendations for California-type climates.

In foundation slabs and for crawl spaces, vapor retarders are essential. They keep ground moisture out of the flooring. There is no debate about the need for this retarder. From a building science perspective, the lower the perm rating, the better (usually 0.3 perm for slab foundations). The more widespread controversy until recently concerned the best location for the foundation vapor retarder. Now, there is a consensus from concrete and flooring experts that the retarder should be positioned immediately beneath the concrete pour, rather than lower down, under the gravel that forms the capillary break under the foundation.

In walls, the current consensus from building scientists is that interior vapor retarders are usually counterproductive in the mild-temperature, mostly-dry climates typical of most of California. In such climates, there is very little vapor-drive outward, because it's not all that cold outdoors, except for a few days each year.

Under such comparatively mild outdoor temperatures, the positive role intended for cold-climate vapor retarders does not apply. Retarders are designed to prevent high indoor humidity from slowly but constantly forcing water vapor into the walls where it would condense. In mild climates like most of California, their more probable role is negative–a vapor retarder membrane can trap water leaks inside walls and also inhibit the release of construction moisture to the drier, air-conditioned environment inside the house.

Naturally, given the climate diversity of California, there is an exception to this advice for the two coldest climate regions of the state (Zones 14 and 16). In the high, cold climates of the mountains, an interior vapor retarder is useful. It should be located just behind the interior wallboard of all exterior walls and behind the ceilings of the occupied space on the top floor. The retarder will keep indoor humidity from migrating outwards and condensing in the walls or attic during the winter months. That's why, when the house is located in climate zones 14 or 16, California Energy Standards require vapor retarders in the walls. Also, in all parts of the state, any stucco wall needs a water-resistive barrier (often a vapor retarder) for protection of the sheathing *inside* the wall.

However, vapor barriers–such as impermeable paint–on the *outside* surface of exterior walls are not useful in any part of California. It's always better to let wet walls dry outwards, because there are so many hours during the year when such drying can take place. Avoiding vapor barriers on the exterior face of walls is a good way to reduce mold risk in all climates–and especially those in California.

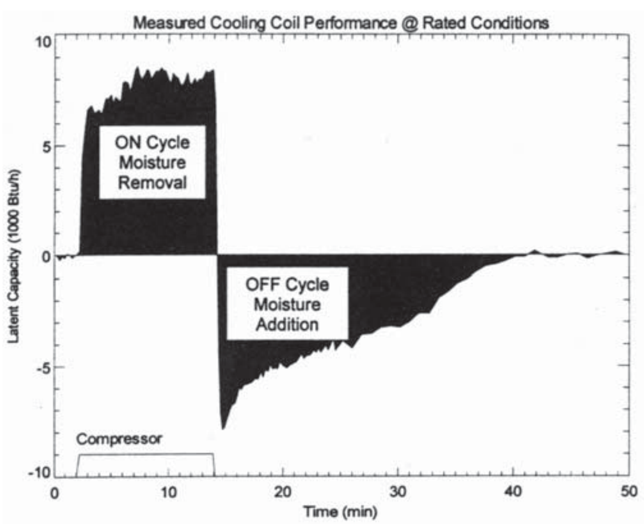
AC system which dehumidifies

In California, humid outdoor air infiltration and dehumidification are not common problems. Most of the state has a dry climate, and even in zones where humidity rises periodically, it does not stay high for very many of the hours in a year.

On the other hand, some homes are occupied on a seasonal basis. Humidity can build up during unoccupied periods because the cooling system may not operate long enough to remove moisture from the air. Similarly, *any* cooling system which is oversized will also have the short run-times which lead to high indoor humidity. "Right-sizing" the AC system helps avoid high indoor humidity, which in turn reduces mold risk. This suggests the designer (and builder) should avoid the usual temptation to install "extra" cooling capacity. Here's why, in more detail.

Modern cooling equipment has become very efficient at removing heat. This means it does not have to run for very long to cool the home. Most of the year, an AC system only needs to operate for a few minutes every hour to keep the home at a comfortable temperature.

Dehumidification is a different story. Typical residential cooling systems must run for at least 20 continuous minutes in every hour to remove any moisture at all from the air. If they don't run for at least 20 minutes continuously, the cooling coils simply don't stay cold enough for long enough for moisture to condense and drip off the coil and into the drain.



So with most cooling systems, the compressor operates for a just a few minutes, just long enough to satisfy the thermostat. Then the compressor shuts off and the coil stops drying the air. In fact, the air flowing across the cooling coil then reabsorbs the moisture that had condensed on the coil, and blows that excess humidity back into the conditioned space, as shown in figure 3.12. The net effect of these short run-times is two-fold: highly efficient cooling, but entirely ineffective dehumidification.

In well-insulated homes, the situation gets worse when the designer sizes the cooling system with extra cooling capacity–for example, selecting a 3.5 ton unit where the peak load is estimated at 2.8 tons. When loads are low and equipment is oversized, the compressors run for even shorter periods, guaranteeing that the home will be periodically humid throughout the cooling season.

There are two ways to improve dehumidification: "right-sizing" the AC system, and adding a dedicated dehumidifier (DH unit).

Right-sizing the system is an option in the more popular load calculation software that is used to document compliance with California Title 24 energy use calculations. The right-sizing option and subroutine was developed by the Berkeley Solar Energy Group to address shortcomings of generic load calculation procedures when applied to California homes. The generic procedures have frequently resulted in either undersized equipment (houses too hot for many hours), and oversized equipment (houses too humid).

Fig. 3.13

Dehumidification performance of cooling systems

Measured values from field-installed units show that unless compressors operate for at least 20 consecutive minutes, cooling units don't actually remove moisture. When compressors shut off early, the moisture simply re-evaporates back into the air stream.[7]

This explains why oversizing cooling units results in cold, clammy houses. The compressors don't run long enough to dehumidify. Solution: avoid oversizing cooling equipment, so it will run longer and dry more effectively.

But to greatly improve both thermal comfort and drying effectiveness, add a dedicated dehumidifier to the HVAC system. This separate unit responds to a humidistat, not a thermostat. It keeps the air at a comfortable humidity all through the cooling season, providing the dry air which can remove any excess moisture from materials, reducing mold risk.

"Right sizing" the cooling equipment does not have the same reliable drying effect as adding a dedicated dehumidifier. Drying is still only an intermittent by-product of the cooling process. So even right-sized cooling equipment does not reduce mold risk as effectively as installing a dedicated DH unit. But right-sizing cooling does save the cost of a separate dehumidifier, and makes the home more comfortable for more hours of the year, while reducing mold risk.

AC system which does not pull humid air into the house

Pulling humid air into cool houses results in condensation on cold surfaces, which eventually leads to mold. Although most of California is a dry climate, humid air infiltration can still occur, especially when ducts run through crawl spaces and attics.

Suction is created when the ducts and duct connections on the return air side of the system are not sealed up tightly. Through those small leaks, the duct connections pull in extra air as they pass through unconditioned parts of the building. As the system draws air ***out*** of these places, outdoor air and humid air from crawl spaces is *pulled into* the cooled building by the slight negative air pressure created by those those leaking connections. The leakage air volumes measured through field research can be quite large, and the infiltration happens any time the fans are operating–thousands of hours every year.

Until recently, experts only recognized the excess energy costs associated with leaking air ducts. Now such leaks are also understood to be a frequent cause of mold problems, especially on overcooled surfaces. When large amounts of humid air are pulled into small, overcooled structures by leaky ducts, condensation and moisture accumulation are continuous and mold grows quickly. This is the one of the dominant mechanisms of the classic mold problems in hotels in humid climates, and in portable classrooms and manufactured homes through the country.

Duct-leakage mold problems tend to be less extreme in California's dry climates. And in field-built houses, dry wooden framing can absorb some of the condensation. But mold problems can occur in any building in any climate where the ducts–and all the duct connections–are not sealed up air-tight.

In this case, California law is clear. Title 24 requires that all ducts be sealed as if they were high-pressure commercial duct connections. The logic for this regulation was based on energy savings. Sealing duct work reduces the annual heating and cooling cost of most homes by 20 to 30%–a significant benefit to the public at a very modest construction cost. But the regulation is also very important to reducing mold risk by reducing condensation. To reverse a familiar saying; sealing all duct connections "isn't just the law... it's a good idea."

Exhaust fans quiet enough that occupants will use them

In California, the outdoor humid air load is very low, in all parts of the state. But the also-low internal humidity load can increase with occupant density, cooking preferences, and number of indoor plants. Compared to water leakage, none of these loads is very significant.

But the colder the surfaces of the exterior walls, the more important it becomes to exhaust water vapor generated from showers, plants and boiling pots. Mold problems from internal water vapor have been recorded in cold climate zones, but also in overchilled buildings in hot parts of the state.

If the exhaust fans you specify for the kitchen and bathrooms are quiet, chances are better that the occupants will use them. A loud bathroom fan that wakes up one's spouse during a pre-dawn shower is less likely to be used than a remote-mounted, slow speed, quiet fan. And a loud kitchen exhaust that makes it difficult to converse or to hear the TV during food preparation is not likely to be switched on very often.

Remote-mounted fans greatly reduce noise in the occupied space, but generally cost more to purchase and install. The designer can weigh the probabilities based on occupant density. When big families occupy small spaces, and when occupant cooking preferences lean towards slow-cooking and boiling pots, and when the building is located in one of the cold climate zones, the potential for mold problems from internally-generated water vapor increases. Especially under those circumstances, the designer might choose to spend more of the budget on quiet exhaust fans.

Showers and bathtub surrounds need design attention and moisture-tolerant materials

Don Halvorson, a bathroom design consultant with long experience in Southern California, has pointed out that–per square foot–the annual *indoor* "rain load" from a shower is *far* greater than the outdoor rain load on the roof. But the joints around most showers and most combination bathtub-showers are not designed or constructed to the same level of care as roofing connections. They need to be. Otherwise, the shower water will get into the walls and grow mold.

This means that the bathtub needs flashing at the tub-wall connection. The same goes for any tub or shower shelves, and especially any shelf where a window provides a view from the tub-shower area. Also, the walls and floor that connect to the tub need full waterproofing as if they were exterior walls below grade. The designer should expect that these surfaces will get wet, and should specify waterproofing and select backing materials accordingly.

For example, cement board is a far more moisture-tolerant and fault-tolerant material for backing of shower tile than is "green board" (waxed gypsum board). In fact, the January 2006 update to the International Residential Code (IRC) prohibits that material as a tile-backer. Specifying a water-resistive layer between the tub/shower and the sheathing and flooring surrounding that fixture is the best way to ensure that water leaks do not create chronic problems.

In kitchens, bathrooms and laundry rooms, design for occasional water leaks and spills

When water ends up on the floor, it is pulled upwards into gypsum board walls by capillary suction, as shown in figure 3.13. When gypsum board is installed so that it rests on the flooring, it's easy for any water spill or floor-cleaning water to wick up into the wall.

This is one reason that mold is so common behind baseboards after water damage. The spilled water wicks up into the gypsum, but can't dry out because the baseboard acts as a vapor retarder. So mold grows on the paper-faced gypsum board behind the baseboard.

Photos courtesy of moistureDM.com

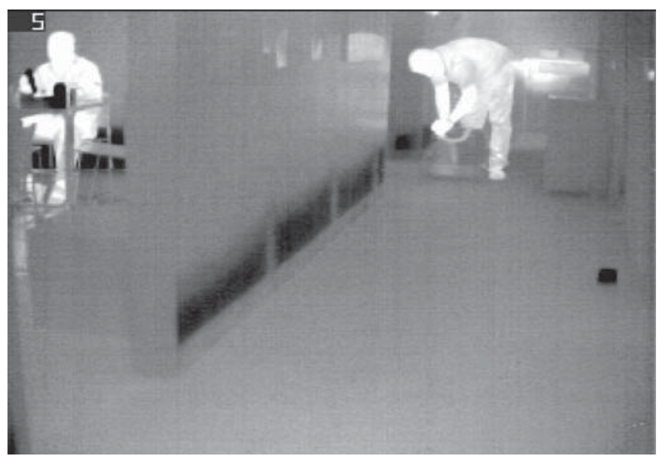


Fig. 3.14

The importance of a gap at the base of a gypsum board wall

This building had a small water damage over a weekend. Because there was no gap between the floor and the gypsum, water wicked up into the wall board, as shown in the infrared image at right. Installing the wall board with a 3/8" or 1/2" gap at the bottom makes any water spill a matter of just mopping up, rather than giving the owner the difficult choice of professional drying or mold growth in the walls.

One solution costs very little additional material: just make sure the gypsum board is installed with a gap of 3/8 to 1/2" at the base of the wall. Then fill that air gap with water-resistant sealant to maintain the sound-barrier and fire protective properties of the wall.

On the other hand, trimming the boards, lifting them, supporting them and sealing the gap takes more time to install, slowing the construction schedule and requiring more supervision and more skill in installation.

So it may be more practical to specify gaps at the floor only in the areas where water spills and plumbing leaks are most likely, such as bathrooms, kitchens and laundry rooms. Alternatively, it may be less costly to specify cement board or fiberglass-faced wall board for these more vulnerable areas.

Total costs and ease of applying final finishes will probably govern the designer's choices. But it's important to recognize the fact that if water spills onto the floor or leaks into a wall, when paper-faced gypsum board contacts the floor in that location, the moisture wicks upward quickly. And it may be difficult to dry out, which increases mold risk.

Specify pans under washers and refrigerators

The most common source of water damage claims against home owners' insurance is burst or leaking hoses which supply water to clothes washers. Leaking water tubing on refrigerator ice makers is another common source of water damage–one which usually falls outside of homeowners' insurance coverage. These leaks are usually small volumes of water, but constant! Because the water leak is not obvious (no puddle), the mold growth caused by ice maker water line leaks is very difficult for the homeowner to diagnose and locate. It will usually happen behind the refrigerator, and may also be inside the wall rather than on its exposed surface.

The designer can reduce the risk of mold from these water sources by specifying pans with drains in laundry closets, and by specifying pans which drain towards the occupied space under refrigerators–mopping the floor is easier than replacing the wall, and bringing the water out in *front* of the appliance alerts the homeowner to the problem.

In the case of washer hose connections, a burst hose will dump many gallons per minute of water into the building. So a pan with a drain is really the only effective way to minimize the catastrophic consequences of a burst hose.

In contrast, leaks from refrigerator supply water lines are slow and small–more like drips than streams. So a pan which simply makes the leak apparent to the owner–by bringing the water forward into the occupied space–will probably be adequate to alert the homeowner to repair the leak, avoiding the need to connect to a drain.

Section 4

Construction

Fig. 4.1 Construction - The key is coordination

In residential construction, many complex, multi-trade joints and corners are left to the field crew to coordinate and install in correct sequence.

It's especially important for supervisors to understand the logic behind the design of moisture-tolerant assemblies, so they can make the right decisions under tight time constraints, and so they will know what to check, and when.

CONSTRUCTION DECISIONS

In construction, the rubber meets the road. All the theory and all the best (and worst) development and design decisions come up against what can really be accomplished by the crews, the subcontractors, the suppliers and... the supervisor.

Given the astonishing complexity of the process and the design, the limitations of time and budget, the random skills and attitudes of available labor, plus the weather–it's a small miracle that anything gets built at all, let alone built in a way that won't lead to mold.

In spite of these obstacles, as one very experienced California construction executive recently pointed out: "We can reduce 90% of the mold risk by simply installing the details as designed, and in the right sequence. The design of the assembly doesn't have to be ideal, and the crew doesn't have to be flawless—they never are. You just have to avoid doing it ***really badly***: by missing one of the components, or assembling it backwards or upside down, or not recognizing the danger of soggy materials."

With this observation in mind, here are some suggestions for the construction phase of the project.

1. Keeping water away

The risks of landscaping and irrigation

In the earlier sections dealing with development and design decisions, we discussed the importance of keeping water away from foundations. But of course, it's during construction that drainage either happens or doesn't.

The finish grading must slope away from the building, and this includes the plant beds near the foundation. And any decorative edging around those beds must allow water to drain away from the building as well, rather than forming puddles of water near the foundation.

1. Note the importance of perimeter drainage when houses are close-set. If this driveway did not drain, water from the roof would flow against the foundation.

2. The finish grading and the driveway both slope away from the foundation, reducing the risk that irrigation water will collect near the building. Otherwise, over time, some water could leak into the house at the foundation to ruin flooring and grow mold.

3. Here's a different home where the grading is not sloped away, so water collects near the foundation every day.

Fig. 4.2 Which way does the water flow?
Water must always flow away from the building, never towards it. Otherwise, as shown above, irrigation water collects at the foundation, increasing the risk of moisture penetration and the resulting mold.

Further, the irrigation spray heads must not spray water up against the side of the building. The siding and window penetrations are not intended to take the large, continuous moisture load of a daily spray of water from below. They're really designed to protect the building from water dripping down from above. So it's important to check that the irrigation spray heads are all directed away from the building, and not towards it.

Dry storage for pre-purchased lumber & wall board

The builder can reduce mold risk by covering any stored piles of lumber and gypsum board to protect them from rain.

Mold on wall board and framing lumber usually grows when these materials are bought in large volumes to get a good price, then left on-site for several weeks until needed for each house.

In California, storing materials on-site without covers does not seem risky, because on average the air is dry. That's why lumber is usually green or just air-dried in California. Historically, green lumber dries out inside the building over the first year or two after construction (which is not done in most other parts of the US).

But every now and then–even in California–it rains. After rain, somebody might notice that the piles of stored wallboard or lumber are now wet. Often, the natural inclination is cover it, to protect it from any further rain.

Unfortunately, covering piles of rain-wetted lumber and damp paper-faced gypsum board to protect it from mold is like dousing a fire with gasoline to extinguish the flames—the tactic has the opposite of the intended effect. The more effective approach is to:

- Store lumber and gypsum board up on pallets, so that rain water or moisture will not soak into the material from the ground.
- Cover the palletized stacks with tarps before it rains.

This approach seems like it costs time and money against a small risk of rain (in most of California for much of the year). But tarps and pallets are probably less expensive than the schedule interruption that comes from having to discard and replace rain-wet material, or paying to dry it out quickly, or waiting for rain-wet material to dry out in the air through natural convection.

2. Keeping water out

During construction, things get wet. There's no way to avoid this, because buildings are built outdoors. At the same time, it's possible to minimize the amount of water that gets into the partly-constructed building, and to sequence the trades so that there's a higher probability of water-tight connections between key components.

Foundation slabs - Avoiding *both* mold *and* cracks

Because of the warping and cracking problems caused by rapid dry-out in desert climates, and because of the difficulty of placing and flowing a "dry" batch of concrete, many builders prefer laying down the vapor retarder first, then placing and pre-wetting a bed of sand or fine aggregate on top of the vapor retarder. The concrete is poured on top of the wetted layer.

The logic for this practice seems strong in some respects. A soaked-sand or aggregate layer immediately under the slab provides a reservoir of extra water, useful in a hot climate to provide the water necessary for complete cure. The extra water also partly compensates for the problem of rapid evaporation from the top of the slab, which leads to poor surface strength and spalling.

Unfortunately, this design also leads to mold and failed flooring. The water trapped in the sand or fine aggregate diffuses upward into the flooring, because it can't drain downwards through the vapor retarder. And California law is now quite clear that the designer and builder are responsible for ensuring that floors do not fail due to moisture coming up through the foundation. (For details, see the discussion in the designer's section of this report.)

So these days, the practice recommended by the American Concrete Institute in their standard ACI 302.1R-04 calls for placing the capillary break (the crushed stone or coarse aggregate layer) first. Then lay the vapor retarder over the stone, and pour the slab directly on top of the vapor retarder.

This is all very well for keeping water out of the flooring. But what can the builder do to avoid the premature dryout, spalling, cracking and warping which may be more likely now that there is no wet layer under the curing concrete? Suggestions include:

- Spraying the slab immediately with a curing compound, to keep the cement and aggregate from separating from the water, which would weaken the surface layer of concrete.
- Using a wetted covering to keep moisture in the slab until it has reached 80% of its ultimate strength–usually 7 to 30 days after pour, depending on the mix.

For a comprehensive visual and technical explanation of ways to install concrete to avoid moisture problems in flooring, the reader is encouraged to consult the book titled *Concrete Floors and Moisture*, written by Howard Kanare in 2005 and published by the Portland Cement Association (www.cement.org).

Logical trade sequence to minimize leaks around windows

Often, buildings leak water around their windows, because the flashing around those windows is either missing or ineffective. Without effective flashing, any leakage stays inside to help grow mold, rather than being guided back outdoors where it can do no harm.

One reason leaks happen at windows is because responsibility is diffused between the window manufacturer, the framing crew and the siding crew, with the construction project manager being responsible for coordination. But this does not always work effectively, because whenever "everybody is responsible," nobody really is.

One way to reduce the risks is to establish a sequence which encourages water-tight connections between windows, flashing and the water-resistive barrier that keeps the water from penetrating into the sheathing and the interior walls.

For example, it's common to have the framing crew install the windows, and then have the lath and plaster crew later install the water-resistive layer along with the stucco. Sometimes, the days-apart separation of these two operations leads to gaps and leaks.

As an alternative, if the framing crew first installs the water-resistive barrier, and then that same crew installs the windows, the probability of a water-tight connection between WRB and window flashing is much higher. The bottom line is that if you often have leaks, consider a different sequence as part of the solution.

Fig. 4.3
Avoiding cracks and surface defects in dry climates
Keep the concrete wet after finishing, then use either a sprayed liquid curing compound or a plastic sheet to ensure that enough water stays in the concrete to cure properly, These measures minimize common cracking, warping and surface spalling without the need to saturate the underlayment—water which eventually diffuses upward to support mold growth in flooring.

Spray lubricant on stucco "weep screeds" to drain water

At the bottom of a stucco-clad wall, the metal "weep screed" provides a firm support to protect the edge of the stucco from crumbling, and it acts as bottom flashing to force any water flowing down behind the stucco back out of the wall.

But field problems with mold in the sheathing behind the lower part of stucco walls indicate that the weep screed may not always let water drain out of the bottom of the stucco before it penetrates imperfections in the water-resistive barrier.

Laboratory experiments confirm that stucco can adhere so tightly to the metal that no water can get through the joint. When that joint is clogged, the only way the wall can release the water is to dry it slowly out the front of the stucco, instead of the much faster and more effective mechanism of gravity drainage.

To avoid moisture accumulation in the stucco at the bottom of the wall, the designer can specify that before the stucco is applied, the plaster and lath crew must spray the weep screed and any control joint metal with household lubricant (while being careful not to overspray onto housewrap, because oily lubricant would let the housewrap transmit water instead of excluding it).

Fig. 4.4 Spray oil on the weep screed to provide free drainage
If the stucco bonds to the metal, water behind the stucco cannot drain freely out the bottom of the wall.

Fig. 4.5
Lab studies show the importance of a bond-break at the weep screed
When the bond between stucco and weep screed is broken, water can drain freely, as seen in the upper photo. Otherwise, water backs up in the stucco as shown in the lower photo, feeding the growth of mold in the sheathing.

This simple measure prevents the stucco mix from adhering tightly to the metal. Later, in a rainstorm or during irrigation spray this "bond-break" allows any water to drain rapidly out between the stucco and weep screed, instead of forcing accumulation in the lower part of the stucco.

Measure moisture in wood framing before "rocking the walls"

Wet framing lumber does indeed dry out over time, and therefore seldom grows mold. But where does that moisture go, exactly?

To avoid mold growth in gypsum board caused by wet framing lumber, it would be prudent to make sure the maximum moisture content of the framing is below 19% before the wall board is placed in the home.

The research in this area is weak, because it is not based on mold in completed building assemblies–which are both more robust and more fragile than these same assemblies in the laboratory. So the 19% maximum for the supporting frame is not a guarantee that no mold will grow on the wall board. Also, buildings have been built with wood framing moisture levels near 19% without problems. It all depends on what is next to that moist wood, how wet the wall board is at installation, how quickly the moisture leaves the wood, whether any trim or wall covering traps that moisture in the wall board, and many other factors.

But overall, forensic building investigators in California have noted an association between wood framing moisture over 19% and mold growing on paper-faced gypsum wall board.

The US Department of Agriculture's *Wood Handbook* suggests that wood for framing be below a 15% average moisture content, and without a reading above 19%, largely to minimize the dimensional change and warping that happens as the framing dries. (The Canadian Wood Council and the recommendations in the *Gypsum Construction Handbook* also agree with 19% as a maximum.) In most parts of California, wood dried indoors will dry down to about 8%. So the dimensional change and drying stress that occurs between 19% moisture content and 8% moisture content is already substantial. For example, a two-story house is likely to shorten by about 3/4" as the framing lumber dries from 19% to 8%. An initial moisture content higher than 19% would only increase the probability of nails popping out of wall board, or wall-ceiling joints cracking open, or chimney flashing coming loose as the framing dries and the frame adjusts to the new dimensions of the lumber.

Fig. 4.6
Moisture measurements
Things get wet—and they might stay wet enough to grow mold after everything is closed-in.

The only way to know for certain is to measure the moisture content of framing before hanging wall board, and measure wall board before painting or hanging cabinents.

So measuring wood moisture content and making sure the frame is dry before applying wall board makes sense both to reduce mold risk and to minimize callbacks caused by aesthetic problems.

Measuring moisture content is very simple. Just push the pins of a moisture meter into the wood and take the reading. Deciding *where* to measure and *how many* places is more complicated. Research is not extensive regarding measurement locations and measurement frequency to be sure of avoiding problems.

Until better-supported recommendations are available, the builder might consider taking some advice supported by a report to the Canadian Mortgage and Housing Corporation.[1] Take several moisture measurements along the length of the sole plate, and two measurements on several vertical studs in each wall: at the base of the stud, and about halfway from the floor to the ceiling. If any moisture reading is above 19%, then take more readings on that wall to see if all of its framing is wet, or if the members are only wet where the initial measurements were taken.

Measure moisture in wall board before paint and cabinets

Wet wall board grows mold. Strong cautions are given by the gypsum manufacturing industry and the installers' associations to "make sure the wall board is *dry* before applying finishes." Unfortunately, these industries and the field research are silent on exactly *how dry* the wall board must be to ensure that finishes will not fail and that mold growth will not happen. That's probably because no single moisture content number covers all cases.

Oops!
*The supervisor, driving by to check on progress, sees the roofers did not take time to tuck the **roofing paper under** the housewrap. Any water flowing down the housewrap will get right into the roof sheathing.*

Call'm back!
The roofers are literally out to lunch. The supervisor calls them back to show them how the lap must be installed.

Show them... don't just tell them.
*The supervisor pulls up the housewrap, showing the crew how it must lap **over** the roof paper, avoiding a major potential mold problem.*

Fig. 4.7
Building the way it was designed
It doesn't have to be perfect... just not really bad. Installing something the way it was designed solves most problems, but that's not always as easy as it sounds when more than one trade is involved in joining separate assemblies.

Anecdotal experience from forensic investigators suggests that a maximum moisture content of 0.8% is seldom associated with mold growth, but that 1.1% is often observed in moldy wall board. When wall board moisture content is measured with a wood moisture meter (much easier to find and less expensive than meters with gypsum scales), a gypsum moisture content of 0.9% would read as roughly 16% softwood moisture content. (Investigators sometimes record this reading as the "Wood moisture equivalent," or they abbreviate the description as WME).

So perhaps until comprehensive research or more explicit guidance from industry becomes available, it might be useful to use 0.9% (or 16% as measured by a wood moisture meter) as an indicator that gypsum wall board is "dry enough" to apply finish, and to avoid mold growth.

Sequencing (and supervision) to ensure it's built as designed

When different trades meet at a corner, who goes under, and who goes over? Unless both workers know the answer, and know why it is important, there's only a 50-50 chance of correct assembly. And with water, the consequences of the wrong guess are quite problematic. Figure 4.7 shows one example. The designer, builder and supervisor all knew that the roofing paper must lap under the housewrap—but the guy installing the paper either didn't know that, or didn't care. The supervisor caught this one, because the fault is obvious to him, and because he understands the consequences. The key is to pass that understanding along to the workers, and give them enough time so they can install the design the way it was intended.

Fig. 4.8
Plumbing leaks are all too common after construction

This photo serves as a reminder of the number of potential leak points in the plumbing system. Every connection is vulnerable, and of course there's always the possibility of nail punctures....

One builder has a standing contract with a drying service because the problem is so frequent. One way to reduce the frequency is to require photo documentation of the pressure test that all plumbers are supposed to accomplish.

Require documented plumbing pressure test

With flexible, cross-linked polyethylene tubing (PEX), plumbing of water lines is much faster than in the past, with fewer joints. But water leaks after construction remain a significant cause of mold problems. Although codes call for pressure-testing of the water supply lines, the test is not always documented well, perhaps reflecting some occasional shortcomings in this area.

The builder can reduce his risk of mold by insisting on documentation of the pressure test results, including the clearly printed name and contact information of the tester, the date of the test and the starting and ending times with photographs of the measured pressures with time and date stamps on the photos.

Documentation of the required test should not add cost to the plumbing subcontract, and it will clearly indicate to the installer that leaks are not acceptable. The documentation will also help establish who is responsible for leaks if they occur later in construction, or during ownership–reducing the financial risks of mold for the builder.

Check and set the arc of irrigation spray heads

Rotating spray heads are not always checked and adjusted at the end of the project, and the homeowner may not be aware of the importance of keeping water off the building.

It is a small matter requiring very little time and cost to check the angles and to adjust the start and end points of the spray heads. But making sure that daily spray water stays off the house is a major reduction in the net annual water load, and therefore a major reduction in mold risk for all parties.

3. Limiting mold growth

Make sure spray-on cellulose insulation is dry before covering with gypsum wall board

Spray-on cellulose insulation is a very effective insulator, and it helps seal up cracks, improving the air tightness of the exterior wall. But it goes on wet.

Spray-on cellulose must not be covered up until it has dried down to a moisture content low enough to avoid transferring excess moisture to the more mold-vulnerable wall board which covers it. The cellulose insulation itself might be treated to limit mold growth, but the moisture it contains can play havoc with nearby materials.

Use a wood-based moisture meter with long, insulated probes to penetrate all the way to the back of the cellulose—to the insulation in contact with the sheathing. As a rule of thumb, if the cellulose moisture content as measured on the softwood scale reads under 16%, it's probably dry enough to cover with wall board. But:

- The manufacturer of the insulation will have specific guidance on this topic.
- If the interior walls are to be covered with material that inhibits drying (like thick paint or vinyl wall covering), the risk of trapping moisture and growing mold is much higher.
- If the gypsum board has been treated with fungicide, it may be less sensitive to mold growth from drying insulation.
- "Factory-dry" gypsum board will measure less than 8% moisture content when measured with a typical

wood-based meter, and under 0.5% when measured by a meter designed only for gypsum. If the gypsum board has been left out in the rain or is otherwise partly moistened, it may be very vulnerable to mold growth catalyzed by additional moisture from the insulation, so a lower insulation moisture content will be needed to prevent a problem.

Dry to keep the project on schedule

It's all very well to recommend keeping materials dry, and using dry framing lumber. But what happens to the schedule when things get wet in spite of good precautions? There are two choices, neither of which is especially appealing:

1. Keep moving. Enclose wet materials, hope for the best and add money to the warranty reserve to cover the cost of some percent of failure.
2. Dry out the wet material with dehumidifiers, blowers and/or a drying service, adding cost and possibly another trade to the job.

The "keep moving" tactic may be the most common and highest risk approach. But in some cases it's appropriate, such as when the excess moisture is confined to a part of the structure that's likely to dry out, and the weather is likely to be dry, and any gypsum board will remain unfinished—as in a semi-finished garage.

In parts of the house that would require costly repair, such as bathrooms and kitchens, or rooms with extensive finished woodwork, drying quickly with fans and dehumidifiers is probably the most certain way to minimize risk and keep the schedule on-track. Heaters may also be useful for drying, provided they are indirect-fired. Direct-fired heaters add a great deal of moisture to the air, and are often counterproductive. For more extensive wetting situations, it may be less costly to employ a drying service company. This is a robust and competitive industry, which has grown nationwide during the last 20 years to help minimize property insurance losses.

Consider applying mold-resistant sealer to gain drying time

Sometimes when construction gets wet it's not practical to dry it quickly. Or in other cases, the amount of moisture remaining in the framing might be a concern for the wall board, but not for the frame. In those cases and others, the builder might consider spraying a mold-resistant coating, often called a sealer, onto mold-sensitive materials that run a risk of absorbing moisture as nearby wet material dries out. Coatings, such as that seen in figure 4.9, can provide a measure of insurance against mold growth during a temporary high-moisture condition during construction.

It's important to keep in mind that drying is the only certain way to prevent mold. But the more mold-resistant the material, the longer the drying time can be without mold growth.

Fig. 4.9
Mold-resistant sealers can extend safe drying time
It's always better to keep materials dry, or to dry them out quickly when they get wet. Ultimately, keeping materials dry is the only certain means of preventing mold growth. But when the construction moisture is temporary and not extensive, or when you seek an extra measure of insurance against occasional small leaks, a mold-resistant coating can reduce mold risk for moisture-sensitive materials, which essentially buys drying time for the building.

How to deal with mold if it grows during construction

If the building grows mold before it is occupied, you can be sure that its materials were much too wet to close in, or that the joints are very vulnerable to water intrusion. In either case, the problem is not likely to be inexpensive to fix. The basic answer to mold problems is:

1. Figure out why the materials got wet enough to grow mold, and stop the source of the moisture.
2. Remove the moldy material right away. Use personal protective equipment to avoid inhaling the fungal fragments and cover exposed skin to avoid skin contact. Pull moldy materials and assemblies apart gently; don't hack them up so that fungal fragments and contaminated dust fill the workers' breathing zone.
2. Measure the moisture content of remaining materials near where the mold grew. If they are still damp, dry them out.
3. Photograph, measure and record the moisture content of the materials after they are dry, to document the fact that they are not only free of mold, but do not have enough moisture in them to grow mold in any new materials.
4. Rebuild the affected area with new, dry material.

This advice is informed by guidelines published by the US Environmental Protection Agency's Indoor Environment Division in 2001.[2] Their guidelines were intended for mold remediation in schools and commercial buildings after they have been built and occupied. There are currently no mold removal guidelines intended specifically for residential buildings still under construction.

From what is currently known about the health effects of moldy building materials[3], it's clear that it's a bad idea to breathe building-related mold, or ingest it or to rub it against your skin. It's also clear that some people are more sensitive to building-related mold than others, and that people who are not currently sensitive can become sensitized after repeated exposure. So in addition to being concerned with the future occupants' health, the builder should take precautions to protect workers from fungal exposure. The appropriate levels of protection are not clear in a construction situation. But in general, the more the space is enclosed, the greater the risk to workers removing moldy material. So mold which grows later in the schedule requires more care in removal than at early stages when the building may still be open to outdoor air dilution.

During construction, it's nearly always less costly to remove and replace moldy materials than to attempt to clean them to a level of cleanliness that would avoid respiratory irritation (or worse) in sensitive occupants. But to explore this option, a builder can review guidelines developed for mold remediation by the cleaning industry. Standard S520 was produced by a volunteer committee of professionals supervised by the Institute of Inspection, Cleaning and Restoration Certification (www.IICRC.org). That standard provides highly detailed guidance on how to inspect for and clean up mold in existing buildings. Following the recommendations of S520 is a fairly time-consuming and costly procedure. Cleaning is more suited to long-occupied buildings where there is no low-cost access to removal and reconstruction, as is the case on a construction job site.

Removing mold from a construction project is seldom going to be either quick, easy or cheap. Buildings are completed more quickly and less expensively when materials are kept dry.

Section 5

Ownership

Fig. 5.1 Owner's decisions

The owner makes aesthetic decisions which can either increase or reduce the risk of mold, especially the complexity of the roof, and the choice of paint.

OWNERSHIP

This report is intended primarily for builders, as explained in the introduction. But there are decisions controlled by the owner which will either increase or reduce the risk of mold. We present these in the same format as we have done for others in the construction chain—as elements of the three-part mold risk reduction strategy.

Note that we have abbreviated these points here, because the logic for each item of advice is presented in much more detail under the sections for the developer, designer and builder.

1. Keeping water away

In keeping water out of the building, the owner's most important decisions are aesthetic ones–deciding to purchase a home with risky features, or one which has features with reduce the probability of moisture intrusion.

Roof overhangs reduce the rain load and reduce electrical bills

The wider the overhang, the less rain can reach the side of the building to run into any cracks that exist or which develop over time. When you decide to buy a house with wider overhangs, you're deciding in favor of lower utility bills, and in favor of a big reduction in mold risk. Conversely, when you decide in favor of a home without overhangs, you're deciding to pay more to cool your house, and trusting that all aspects of the rest of the design and construction will be nearly flawless, which is not likely in the real world.

MacGregor Pearce, the noted building scientist and mold investigator, has a useful way of thinking about aesthetic decisions which go against the odds, such as deciding against roof overhangs: "It's sort of like choosing a cute little grizzly bear cub as a pet for your child: it might work out OK for a while... but given time, it's not a safe bet."

Complex roofs are risky

The more corners and joints a roof has, the higher is the probability that *one* of these will leak water, which leads to mold indoors.

At present, many home buyers prefer roofs which have many peaks, valleys, dormers and interesting angles. The simple, two-sided roof is no longer in fashion. But when you buy your home, you may want to keep in mind that when rain hits a roof, it collects and concentrates in those interesting valleys and crevices, presenting a big challenge to the skill and quality control of the roofer and the siding crew, who must make these joints water tight. Fewer joints–less risk.

Plants and irrigation near the foundation are risky

Most home buyers prefer the "settled look" of well-developed shrubs and plants up against the foundation. But this practice increases mold risk in two ways.

First and most importantly, plants are often irrigated daily to keep them healthy and attractive looking. Spraying large amounts of water near the foundation has the potential to create major mold problems if there are any leaks in the building's cladding, or around windows or doors, or at the joint between the foundation slab and the exterior

Fig. 5.2 Foundation shrubs increase mold risk
Tall shrubs block the air flow that would dry out the exterior of the house after rain, or after irrigation. These bushes reduce drying, so they increase risk. Luckily, in this case the ground slopes away from the foundation, so at least water drains away, reducing the risk created by the bushes.

Fig. 5.3 Daily irrigation increases mold risk

As long as the nozzles are not spraying water against the house, and as long as the foundation drainage is adequate, irrigation systems pose no problem. But when spray heads break off over time as shown here, a great deal of water can flood the yard and reach the foundation. Broken or poorly-installed irrigation systems are often at the root of mold problems in dry climates.

siding. The chances are very good that one of these assemblies will leak to some extent. If the irrigation nozzles are not directed perfectly, or if one or more of the nozzles are snapped off, the system can be responsible for daily water infiltration, and the mold which results.

Secondly, the plants themselves shelter the building from wind, preventing the lower part of the building's exterior from drying out after rain or misdirected irrigation.

So in the interest of both water conservation and reducing mold risk, it's best not to choose plantings that must be near the foundation, and to avoid plants which need an irrigation system to survive.

These will not always be popular alternatives. When an owner decides in favor of foundation plantings and daily irrigation, he should be aware that these are risky with respect to mold. To minimize that risk, the owner should, at the very least, ensure that:

- Bushes and other plants are placed *as far away* from the foundation as your aesthetic preference allows, and kept trimmed as low as possible, to let drying air circulate near the foundation behind them.
- The ground *slopes away* from the foundation, not towards it.
- Any decorative edging around the plant bed does *not* form a "landscaper's moat" that would hold excess water near the foundation.
- No spray heads are *snapped off*, which could spill water onto the ground near the foundation.

Adjust irrigation spray heads to keep water off the house

If the irrigation spray heads rotate, it's important that their spray arcs be adjusted so they will not spray water on the house. Some of the most notorious mold problems in California housing have come from irrigation systems that wetted down the walls daily, combined with slight imperfections and wider-than-ideal joints between windows and walls. The spray water gets in through cracks and diffuses slowly through exterior cladding, and mold grows.

Although the builder *might* have adjusted these arcs before turning over the house, he also might not have. And even if he did, the spray angles are bound to go out of adjustment over the life of the building. The homeowner can reduce the mold risk in a major way, for basically no cost, by simply making sure that the irrigation spray heads are not soaking down the building, nor allowing water to pool near the foundation.

Xeriscape (dry landscaping) reduces mold risk

Most of California is a dry climate, which has an inherently lower mold risk than, for example, South Florida with its high water table and constant rain.

But the typical landscaping preference for a green lawn radically increases the water load on California houses, raising the mold risk from any slight imperfection in the exterior walls or foundation. The numbers are staggering. A family home in the Los Angeles area uses *thousands* of gallons per month for irrigation. If any of that water gets into the exterior walls or foundation of your home, it can support mold growth.

To reduce mold risk to the inherently low levels allowed by the dry California climate, an owner can choose xeriscape instead of plants or design features which need daily watering, like grass lawns. Xeriscape relies on native plants and grasses which tolerate lower annual rain rates, or which can thrive with very little irrigation.

Most often, the choice of landscaping is heavily influenced by the owner. If you decide you like the "dry look," you can conserve our national water resources, save yourself money, reduce the time you spend on weekly maintenance and also reduce the risk of mold.

Keep gutters free of leaves and keep rain water away from your foundation

Clogged gutters and downspouts can lead to water flowing down the side of the house instead of being drained away from the foundation. Make sure that water can flow freely through the gutters and downspouts. Then, make sure that when water exits the downspout, it's well-away from the foundation. Two feet away from the edge of the house is a good minimum.

2. Keeping water out

Use highly-permeable paint for exterior stucco

Over time, stucco cracks. That's the fact. When you paint stucco, any moisture that gets through the cracks can be trapped there, and will lead to mold at some point–usually at the bottom of the wall. If you have an option during construction, choose a pigmented stucco mix rather than painted stucco.

If you must paint stucco, as many owners do, recognize that every coat of paint makes it less likely that trapped water will be able to dry out. The thicker the paint, the greater the mold risk.

When you have no choice but to paint, be certain to get a very permeable paint. Ask for paint rated at 10 perm or greater.

Dry out carpets after cleaning

Most commercial carpet cleaners leave a great deal of water in the carpet—gallons and gallons of it. Of course many cleaning companies are more careful to extract a high percentage of the water they spray. But the prudent homeowner will recognize the potential for problems when gallons of water are sprayed into the home, and will make sure that the carpets dry out completely before the drying fans and/or dehumidifiers are shut down after carpet cleaning.

Ask your contractor to demonstrate the fact that the carpet is dry before his drying equipment is removed. When in doubt, step on a paper towel laid onto the carpet. If it comes up damp, the drying is not yet complete.

Don't disconnect the clothes dryer exhaust hose

In all but the cold climate zones, internally-generated humidity is usually not a concern in California. But there are exceptions. One is the classic case of the clothes dryer which vents its humid air into the building rather than to the weather. When clothes dry, they release many pounds of water vapor into the exhaust air. If that highly humid air is not vented out of the home, it will cause problems indoors, and can, over time, lead to mold.

This caution is especially important in cold climates. The volume of condensation is greater when the walls are colder. At the same time, it seems like it might be a good energy saving technique to keep hot air inside the home when it's cold outdoors. It's not a good idea. High humidity indoors leads to mold. Make sure the dryer is venting its exhaust air outdoors, all the time, in all climates.

Recognize that indoor plants evaporate moisture constantly

A few plants are not going to release enough water vapor to cause a mold problem. But if you really enjoy having a dense growth of plants indoors, recognize that they are loading the home with water vapor all day, every day. All of the water you pour into their pots is eventually evaporated into the air. So if you are providing them with many pints per day, it's useful to remember that these pounds of water vapor should be removed from the air, either by exhausting some air periodically, or by running a dehumidifier.

Invest in a low-cost humidity monitor. If you find the indoor relative humidity is constantly above 50%, you might want to consider installing a dehumidifier. If it's constantly above 60%, realize you're running a degree of mold risk more common in humid climates. If it's frequently above 70%, realize that some forms of mold are able to grow in common building materials that have absorbed humidity at that level–even without gross water leakage.

Use your shower and kitchen exhaust fans

Showers and boiling pots are frequent–but small–sources of internally-generated water vapor in homes. Neither of these humidity loads is significant compared to even a small water leak in the exterior building envelope.

On the other hand, if you have many people living in your home and they all take showers once a day, the water vapor load can become a contributor to excess moisture in the walls near the bathroom. Similarly, if your cooking preferences tend towards pots which boil for long periods, recognize that the kitchen air is filling with water vapor.

If you simply run the kitchen and bathroom exhaust fans when these activities are underway, you'll get rid of the excess humidity and prevent any negative effects from the modest amount of moisture generated by these two sources.

3. Limiting mold growth

The longer materials stay wet, the higher the probability they will grow mold. The earlier sections of this report have numerous suggestions for developers and builders with respect to features that can be built into the home to allow it to drain water and to dry out any water quickly. It's useful for the owner to also appreciate the importance of quick drying and to avoid changing the building in ways that prevent fast drying.

Know where the master water shut-off valve is located

When pipes break, it's rather discouraging to watch gallon after gallon of water pour onto the floors and into the walls. So it's a good idea to find the master shut-off valve for the water supplied to your home. That way, there's a better chance you'll be able to find it during a panic situation, and shut it off.

Dry moist materials immediately

Any time you see water inside the home, stop the source, mop it up and dry out the remaining moisture immediately–in as few minutes or hours as possible. Don't wait until the experts arrive to do these obvious things.

Until recently, it was not clear to the insurance industry or to home owners that wetted buildings were any immediate concern. So for years the industry asked homeowners to wait until the adjustor could visit the wetted home before beginning any repairs. That was very poor advice with respect to minimizing mold risk, and typical adjustor case loads have increased ten-fold in the last 20 years, which means mold could grow for days or weeks before any insurance representative reviews the case.

So these days, the advice from the insurance industry is to dry immediately. In fact, some companies may decline to cover all or part of a water loss if the homeowner has not "mitigated the damage" by drying immediately.

This advice is not a substitute for professional drying when the damage is extensive. When a pipe breaks in a winter cottage and the damage is not discovered for hours or days, you'll need professional help to make sure everything has been dried to quantified moisture levels. Also, the level of concern should be equal to the amount and duration of wetting involved. A few molecules of water are not an important mold risk. If the kids occasionally drip water though the house from wet bathing suits, one should not panic about mold risk.

The main point is that your fast response keeps water from spreading into materials which might soak it up. Reducing total water absorption reduces the net mold risk. Also, the longer things stay wet, the greater the mold risk. So try to dry them out as quickly as possible–in minutes or hours rather than days and weeks.

Avoid interior wall finishes which are vapor retarders

When you smell mold but can't see it, chances are good that mold is growing inside the walls because moisture has been trapped inside them.

You can avoid trapping moisture in the walls by choosing *vapor-permeable* paints instead of vapor retarder paints, and by choosing paper-based wall paper instead of vinyl. For paints, look for permeability ratings above 10 and preferably above 15.

Bathrooms are one exception to this advice, and cold climates are another. If the building is located in the cold mountains where the heating season is long, then interior vapor retarder paints are useful, especially in bathrooms and kitchens. You'd like to avoid having interior water vapor diffuse outward into the walls, where it could condense. But except for bathrooms, in most of California, vapor retarder paints are not a good idea. They increase mold risk by keeping the walls from releasing moisture towards the relatively dry interior of the home.

Avoid storing paper and fabric in damp locations

It's futile to prohibit storage in damp spaces. But one should recognize the mold risk and take steps to minimize the dimension of the problem. For example, store papers and clothing in plastic or metal containers, and lift these up on blocks, to avoid direct contact with moist surfaces. And consider using a dehumidifier in those storage spaces, when the environment is damp.

If you see condensation, it's a potential problem

If you see visible condensation on the inside of your home, it's an indicator that moisture is probably building up in the walls at that moment as well.

There's no need to panic when humid air condenses on the bathroom mirror after a shower. But when, for no obvious reason, moisture droplets appear on windows or walls, you can take it as an indicator that the indoor humidity is rather high. When condensation persists over hours, or recurs for many days, it's time to figure out what's causing the high humidity and eliminate the source of the excess moisture.

If you see water stains indoors in a new home, call the builder

When a problem goes beyond slight condensation all the way to water stains, it's time to call the builder if the house is within the warranty period. If the home is older, then you'll need to investigate the problem yourself, or find a building investigator who is familiar with moisture problems in buildings to diagnose the problem and recommend solutions.

If a stain appears after a rainstorm, it's likely that the water came from rainwater intrusion. If the stain does not seem to have any relation to the timing of rain, then it may be related to leaks in plumbing. But these are only the two most obvious of the dozens of reasons that water stains appear, and leak investigations can become quite complex.

If the stains recur, then clearly the problem should be a bigger concern. Documenting the frequency, location and moisture content of the stained materials will be very helpful to the professional who helps you diagnose the problem, whether that is the builder or a third party.

When in doubt, measure moisture content

As most people know, mold cannot grow unless there is enough moisture in its food source. So as a homeowner, when you notice that wall board or wood or carpets are perceptibly wet, it's clear these materials should be dried out. But then the obvious question arises: how dry is "*dry enough*" to keep mold from growing in common indoor building materials and furnishings?

Somewhat surprisingly, at present there are no simple answers to this question. Laboratory results are not as useful as one might hope. In the real world, materials are sometimes more fragile and other times more robust than their behavior in a controlled experiment.

But it may be useful to know that if you measure the moisture content of gypsum wall board or wood products with a moisture meter built for wood, and if the reading is above 16%, it's an indicator that the moisture content is well above the 6 to 8% recommended average for wood products *indoors* in California (USDA Forest Products

11% WME, measured on the dry side

Fig. 5.4 Moisture measurements and mold growth

This series of photos shows that even over a distance of an inch, moisture content can vary widely. In the area reading 11% WME (wood moisture equivalent) this piece of unprotected wall board has grown no mold, even after more than a year of contact with a damp floor. But across the edge of the visible growth less than an inch away, the moisture reads 5% higher. And as the meter moves to the right into more moldy areas, the measurement rises above 19%. When using a wood-based meter, as shown here, a reading of 16% is an indicator that moisture is well above the USDA recommended average of 6 to 8% for indoor wood in California climates. (If this particular gypsum board were "factory" dry, it would read less than 8% on this meter.)

Note: like most readily-available meters, this one is made for wood, not gypsum. A gypsum meter would show readings of 0.4 in the dry area to 1.1 in the moldy area. That's why these readings, taken with a wood meter, are described as WME - wood moisture equivalent. Also, keep in mind that readings are probably only within ±3 to 5% of the true value. (Don't assign much significance to that impressive-looking decimal!)

15% WME, measured across the visible edge

19% WME, measured on the moldy side

23% WME, measured in the moldy area

Laboratory, *Wood Handbook*). Such a reading might indicate that either the material is still drying out after construction, or that excess moisture has gotten into that material from some more current source. Note that materials exposed to the weather *outdoors* change moisture constant constantly, so readings above 16% outdoors are quite common and may be normal.

To be clear, the authors of this report have no intention of implying a maximum 16% moisture content reading on a wood-based moisture meter should be considered a standard. Nor do we mean to suggest that mold will *not* grow below that level. Until more conclusive research can be accomplished, the 16% threshold is simply, in our opinion, a useful trigger point which suggests further diagnostics by a professional.

IN SUMMARY, ADJUST YOUR CONCERN IN PROPORTION TO BASELINE RISKS

Nothing in life is free of risk. Those living in California are well-aware that earthquakes happen, but they choose to live in the State in spite of that risk. One can minimize the risk from earthquakes by deciding not to live near fault lines. Or if that is not economically practical, one can minimize the risk by understanding what to do if an earthquake should occur near your home.

Responding to mold risk is similar. A homeowner can decide not to live in a house that has high mold risk. Or having decided to purchase a house with higher risks, one can minimize these risks by recognizing and minimizing risk factors.

It's not easy to assess mold risk, even for professionals. But you can make a good start by reading the earlier sections of this report and seeing what risk reduction measures can be taken by the developer, designer and builder. Then compare your home (or the one you are planning to buy) to those suggestions.

If your home has been built with more risk factors, you might want to give more attention to any water accumulation. For example, if your condominium building is surrounded by decorative earth berms covered with grass requiring daily irrigation, you would want to make sure that water does not run down the berms and collect near the foundation of your unit. Or if your hillside house extends all the way to the edge of your uphill neighbor's property line, you might want to discreetly examine the drainage in his yard to make sure it does not flow water against your walls during a rainstorm.

Similarly, in developments with higher risk factors, it would be appropriate to make sure that *your* irrigation, or roof and yard drainage are not creating higher mold risk for your neighbors.

Section 6

Managing Tradeoffs & Minimizing Unintended Consequences

UNINTENDED CONSEQUENCES

After a long and distinguished career, Eric Severeid, the famous journalist, observed that in his experience "The principal cause of problems is solutions."

Intelligent people take calculated risks with imperfect information in response to dynamic conditions, making decisions that are intended to improve their overall situation. Builders must balance a number of factors in their decisions such as:

- Schedule Impacts
- Product Cost
- Installation Issues
- Durability in Service
- Risk of Failure

When trying to solve complex problems with imperfect information, the decisions will almost always have unintended consequences. These unintended consequences can be foreseeable or hidden, and can range from synergistically better, to neutral, to detrimental overall. The impact of the unintended consequences can be on the problem of interest itself, or can affect another area or stakeholder that had previously not been involved in the original problem. The nature and frequency of unintended consequences makes this issue critically important to the builder.

There are four options for solving moisture problems: Symptom solutions, standard solutions, engineered solutions and mandated solutions. Each approach has unintended consequences that need to be evaluated in a different way to minimize detrimental consequences and create true win-win-win scenarios for all affected stakeholders.

We will describe the trade-offs of each approach, so that stakeholders can be more aware of their options.

Symptom Solutions

These address symptoms instead of the underlying or root cause. Symptom solutions will probably be ineffective or make the problem even worse, and may have other consequences, some possibly good, others possibly bad. This situation is to be avoided if at all possible because the probability of successful resolution is very small and the risks of major unintended consequences are great. Symptom solutions are usually responses to crisis mode problems that require expert diagnostics and root cause analysis very quickly. Time pressures to "do something right away" add to the likelihood of "symptom solutions," especially during the construction period. In addition, these solutions are often very costly to implement since there is no time to optimize the solution.

Standard Solutions

These apply standardized approaches to root causes of a problem and can be very effective if the causes are not too complex. However, for more complex problems, the root causes are usually also complex and difficult to address, and may not be amenable to standardized treatment. Misapplication of a conventional solution that attacks only part of the root causes can have even more unintended consequences than symptom solutions.

Engineered Solutions

These apply building science and engineering principles to targeted problems and their root causes. These solutions are intended to address complex problems and complex causes by detailed analysis and designs. They are typically expensive to design, but may be the least costly option and offer the best chance to make all stakeholders better off (creating the win-win-win scenarios). Engineered solutions rely on consensus standards coupled with specific expertise and engineering judgment as well as regional biases. Even in the best engineered solutions to complex problems, there are still unavoidable unintended consequences and design tradeoffs.

Mandated Solutions

These are code-enforceable and actionable solutions to a host of design problems, without necessarily considering underlying causes. These solutions have time lags built into them and are typically conservative, with slow adoption of mandated approaches. Mandated solutions usually rely on industry consensus standards as the basis of code enforceable language and usually offer the option of engineered solutions. Numerous unintended consequences of mandated solutions have been documented.

Unintended consequences always happen

Considering the numerous tradeoffs in house development, design, and construction, almost all substantive decisions will have other unintended consequences that can make the overall situation worse – and not necessarily in the area being addressed, or for the originally affected stakeholder. The builder needs good, unbiased information about the problem and its consequences, sound technical solutions based on conservative practice, and proper implementation for overall improvement.

It is especially challenging to avoid or minimize unintended consequences when addressing mold problems because conservative solutions may be difficult and costly, and data on root causes is limited, anecdotal, or misunderstood. Pressure to "do something" right away can cause uninformed or misguided decisions that may make the initial symptoms go away, but create a worse overall problem in another area. Often, it is easier to purposefully choose to ignore or accept the unintended or foreseeable consequences than to explore creative alternatives that "might" work better.

Unintended consequences also can add enough to the overall cost or risk of proposed solutions to make them unwise even if they solve the original problem. For instance, barrier EIFS was intended to be a very cost-effective energy efficient wall construction. Unfortunately, the nature of the cladding was fragile and had no backup drainage capability if the barrier was breached. While EIFS with drainage mats have addressed this unintended consequence, the damage to the EIFS industry and its customers was massive – and totally avoidable.

The lack of data on causes and consequences of mold problems, combined with a rapid increase in litigation, created such an unquantifiable risk that insurance companies now have mold exclusions as the norm. For builders, the law of unintended consequences affects both budget decisions and risk-averse, conservative behavior. If they aren't sure the proposed solution is better than their tried and true methods (e.g., ACI 302.1R-04 guidance on vapor retarder location), they will be slow to adopt it, even if it is a seemingly robust and cost-effective approach. This puts a large burden on building scientists to show the efficacy and robust nature of solutions as well as their foreseeable consequences when installed in a variety of applications.

Making practical decisions

Intellectual property, marketing initiatives, and standards (or lack thereof) can be powerful agents of unintended consequences. To defend against market imperfections, it may be wise to follow a slower, but solid voluntary approach to identifying, researching, designing, and implementing solutions to important problems like mold.

1. Identify the problem of interest and knowledge gaps about the problem and its causes.
2. Perform targeted research on potential solutions and related information.
3. Develop intellectual property to implement solutions and information for standards actions to educate the engineering community and qualify the solutions.
4. Commercialize and improve solutions in the free market when there are no market disconnects (e.g., beneficiary doesn't or won't pay for the solution).
5. For market disconnects, implement rational regulations that rely extensively on voluntary standards (e.g., ANSI) and associated technical justifications.

Engineered solutions typically work well for targeted problems. However, they can have a spectrum of other impacts for untargeted areas. For example, a high permeance water-resistive barrier is an excellent method of keeping water out while letting vapor through. This solves one type of problem faced by builders – how to keep water out of the wall while letting vapor flow and keep the inside of the wall cavity relatively dry. This technology can actually create another problem when it permits the vapor to flow freely if the interior of the wall is cool enough (e.g., air conditioned spaces in humid climates such as Florida) to allow that vapor to condense, because the water-resistive barrier will then act to keep the water in the cavity where it can do damage.

There are numerous problems that might occur under certain combinations of circumstances whose solutions are at odds with other high probability scenarios and problems. These conflicting situations and scenarios force the developer, designer, and homeowner to make tradeoffs and economic decisions that are intended to reduce the net risk, or possibly the risk of the more likely situations at the expense of increased risk for less likely situations.

Getting Involved in Voluntary Standards

Voluntary consensus standards work best to minimize unintended consequences when all affected parties are involved in creating and updating them. The slow, deliberative nature of these standards processes has been likened to making sausage: The final product can be very good, but you really don't want to know how it was made. Unfortunately, letting others develop these standards might result in new regulations or codes that add cost or limit flexibility of designs without full consideration of the overall impact. It is important for builders, designers, and homeowners to get involved in local, state, and national codes and standards processes to have their viewpoints adequately considered. This is often not easy, but the alternative is to let others decide the future and trust that they will get it right. Getting involved is as simple as volunteering and showing up at meetings, and it can be very rewarding to provide a positive influence on the future quality of new homes.

Final Points

Houses in California face very different environmental factors (sun, wind, rain, soil, earthquakes, floods) than houses in the Southeast United States. For this reason, no single approach will work well in all situations. Still, all houses face a number of common challenges during their lives such as rain, landscape irrigation, groundwater, interior moisture loads, structural leaks, and plumbing leaks. Durable, affordable houses require the developer, designer, builder, and homeowner to make informed choices that always implement the most cost-effective solutions to common problems, and to make intelligent tradeoffs that improve system performance for the unique challenges faced by each house in its specific location.

Section 7

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