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A Field Study of Indoor Moisture Problems and Damage in New Northwest Homes

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ABSTRACT

The interior living spaces and the ventilation systems of 86 newly constructed houses in the Pacific Northwest were inspected to determine if building them to energy-efficient standards with more insulation (at least R-19 [R-3.3] in walls) and relatively airtight with an air-vapor retarder causes indoor moisture problems or damage. The test houses were located in three climatic regions: 50 in the metropolitan Seattle-Olympia area, 16 on the rainy Washington coast, and 20 in the cold Montana region.

Numerous moisture-related problems were observed within the homes, primarily because of inadequate moisture control and consequent high indoor relative humidities. One-third of these new homes had mold and mildew on indoor surfaces such as walls, one-third had mold and mildew on window frames and/or sills, almost three-quarters had condensation on window glass and frames, and one-quarter had window sill damage as a result of the window condensation.

A majority of the ventilation systems, including spot exhaust fans and air-to-air heat exchangers (AAHX), were not working as well as expected or were not being used by the occupants. Overall, for a variety of reasons, there was no AAHX ventilation in about one-third of the homes, no kitchen ventilation in almost two-thirds of the homes, and no bathroom ventilation in about half of the homes. Of the bathroom exhaust fans that did work, the actual exhaust flow of the systems, including ducts, that were measured was only about half of the rated capacity of the fans. All of these ventilation system problems resulted in inadequate removal of excess moisture.

The findings of the study dramatically point out the need for better indoor moisture control in these and probably other new homes. For future tightly built homes, moisture control must have a much higher priority in their design, construction, inspection, and ongoing operation. Specific recommendations are made to improve indoor moisture control through better ventilation, including automatic control, and dehumidification.

INTRODUCTION

Indoor moisture-related problems, such as dampness and mustiness, window condensation, window sill damage, and mold and mildew, are known to occur in older homes. For example, in Portland, Oregon (4732 DD), and Spokane, Washington (6835 DD), 93 and 103 older homes, respectively, were carefully inspected for indoor moisture problems (Tsongas 1980, 1986). Condensation on windows (almost all had storm windows) was noted in about two-thirds of the homes, and mold and mildew were observed on window frames and on interior surfaces such as walls and ceilings in about one-third of the homes. In about one-quarter of the homes, the clothes dryer was vented inside the house, and almost half the homes with a crawl space had no ground cover. The average indoor relative humidities measured during the winter were 56% for the Portland homes and 47% for the Spokane homes, with many homes having relative humidities in the seventies. During the fall and spring, the indoor relative humidities would be even higher. Thus, the homes clearly had interior moisture problems, in large part due to lack of satisfactory indoor moisture control. It is generally believed that the lack of moisture control is tied to the lack of adequate ventilation.

In newer, more heavily insulated homes, it might be anticipated that the additional insulation levels would warm surfaces and reduce the incidence of interior surface mold and mildew. Furthermore, the use of better windows (often triple glazed) ought to reduce window condensation. Because the newer homes are more tightly built, indoor relative humidity should increase and with it the incidence of indoor moisture problems (Tsongas 1987). However, that ought to be offset with the inclusion of better indoor ventilation systems, such as spot exhaust fans with air-to-air heat exchangers (AAHX). Thus it has been felt that indoor moisture problems should not be as prevalent in newer homes as in older homes. Unfortunately, there have been few field data to verify that belief.

As a result, the Northwest Wall Moisture Study (Tsongas 1990) was undertaken in 1986 with one major goal—to document any moisture-related problems that exist inside heavily insulated, relatively tightly constructed new homes built in the Pacific Northwest. The extent of indoor moisture problems was of concern because of the surprisingly large number of complaints about moisture problems in these new homes. This paper describes the indoor moisture problem portion of the field study. The results and findings reported here are presented in considerably more detail than in Tsongas (1990), which has not been widely circulated.

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STUDY PLAN AND FIELD TEST METHODOLOGY

The goal of that part of the study described in this paper was to carefully inspect new heavily insulated and relatively airtight Northwest homes and document any moisture-related problems that might exist inside the homes. Houses were selected from two regions that experience climatic extremes (the Washington coast and Montana) as well as a major Northwest population center (Seattle-Olympia, Washington). The 86 homes selected were chosen from 257 randomly selected, single-family homes, almost half of which had moisture problems. The homes were visited during the winter of 1987; the occupants were interviewed to determine pertinent life-style characteristics, and the homes were carefully inspected to assess indoor moisture-related problems.

The homes were checked inside and outside in detail for leaks, moisture, or moisture damage. Indoor relative humidities and temperatures were measured in many rooms of each house using a highly accurate digital humidity and temperature meter. In addition, the ventilation and dehumidification systems were identified, inspected, and tested to see if they were working. The volumetric flow rates of the bathroom exhaust fan systems were measured using an unbalanced flow hood developed for the project's sponsoring agency. The results were loaded into a microcomputer data base. A detailed statistical analysis of the data was undertaken to try to determine the "causes" of the moisture problems that were found.

TEST HOME AND OCCUPANT LIFE-STYLE CHARACTERISTICS

Selected house characteristics are presented in Table 1. A detailed description is presented in Tsongas (1990). All the test houses were electrically heated. They ranged in age from a few months to a few years old. Note that 73 of the 86 test houses had an air-to-air heat exchanger, and the others used a dehumidifier to remove indoor moisture. At the time of the study, whole house exhaust-only ventilation was not in use in the region.

The test homes were relatively tightly constructed, especially relative to older homes in the region. All had some type of air-vapor retarder system in place and had at least R-19 (R-3.3) wall insulation. Heating season natural infiltration air change per hour (ach) values for 34 of the homes were obtained from previous blower door tests using the standard methodology (ASHRAE 1989). The mean ach values for the homes in each of the regions are: coastal, 0.22; cold, 0.30; metro, 0.27; all, 0.28. Air change rate results were available for only one coastal house, 16 of the 50 metro houses, and 17 of the 20 cold region homes. Thus the mean values may not be representative of all the houses in the metro and coastal regions. In part, given the lack of polyethylene in half of the coastal houses, they are probably leakier than the one 0.22 ach value would suggest.

RESULTS AND FINDINGS

Indoor Relative Humidities

The living room temperatures and relative humidities measured during the winter are presented in Table 2. Overall the RH values are fairly high, although the high values in all three regions are not unexpected given the tightness of the homes and the climatic conditions (Tsongas 1987). Many of the high indoor RH values may be associated with relatively low indoor temperatures. Indoor relative humidities should be even higher during the milder fall and spring weather when the outdoor air is considerably more moist, and so ventilation is less effective at flushing out moisture generated indoors.

The relative humidities were lowest in the cold region and highest in the coastal region, as expected. The mean relative humidity for the coastal region homes was very

TABLE 1
Selected Test House Characteristics

	Cold	Coastal	Metro	All
No. of Test Homes	20	16	50	86
Wall Air-Vapor Retarder Types				
Interior Noncontinuous	0	8	9	17
Interior Poly, Walls Only	0	3	1	4
Interior Poly Wrap	19	2	29	50
Interior Foam Sheathing	1	1	10	12
Exterior Foam Sheathing	10	0	15	25
ADA (airtight dry wall)	0	4	2	6
AAHX	20	10	43	73
Dehumidifier	1	6	7	14
Triple Glazing	13	7	24	44
Wall Insul. Mean R ($m^2 \cdot K/W$)	5.8	3.5	3.9	4.2
($ft^2 \cdot h \cdot {}^\circ F/Btu$)	33	20	22	24

TABLE 2
Wintertime Living Room Temperatures and Relative Humidities

		Cold		Metro		Coastal		All	
RH (%)	Avg	40		47		53		47	
	Max	55		63		75		75	
	Min	23		33		39		23	
	StdDv	8		7		9		8	
Temp (°F) [°C]	Avg	68	[20]	66	[19]	67	[20]	67	[19]
	Max	77	[25]	75	[24]	75	[24]	77	[25]
	Min	58	[14]	54	[12]	57	[12]	54	[12]
	StdDv	5	[03]	5	[03]	5	[03]	5	[03]

similar to the 56% average measured in the older homes of the Portland study (Tsongas 1980). The 47% average value for all homes, as well as for those homes in the metro region, was almost identical to that for the older homes of the Portland study (Tsongas 1986). Relative humidities often were measured in other rooms, such as kitchens, bedrooms, and bathrooms; they are available in the data base (Tsongas 1990). For the most part, they were very similar to the living room relative humidities. Bedrooms were often kept cooler and hence had somewhat higher relative humidities in those cases. The highest RH value measured in this study was 85%, which occurred in a cold bedroom of a coastal house whose AAHX did not work properly.

It is important to note that about half the homes have relative humidities that are higher than the average values in each region. Those high values measured in this study point out the lack of proper moisture control in many of the homes. The high average for the coastal homes suggests a lack of sufficient moisture removal in many, if not most, of those homes and also reflects the higher humidity of the outdoor air.

Indoor Moisture Problems and Damage

Engineers visually inspected the 86 test homes in considerable detail both inside and outside every room, as well as in the attic and in the basement or crawl space. As seen in Table 3, moisture problems or damage were observed during the home inspections in a relatively large percentage of the homes in all three regions. Somewhat surprisingly, almost all the problems were worst in the cold climate. Window moisture problems were common. Almost three-quarters of the homes had condensation on window glass or frames, while one-third had mold and mildew on window frames and/or sills. One quarter of the homes had moisture damage to window sills. While some condensation, and even mold, is to be expected, the high frequency of occurrence of window problems was unexpected in these new homes that had improved window systems (half were triple glazed) and presumably had well-controlled interior conditions.

In addition, previous moisture or water leak problems were reported by 83% of the occupants (see Table 4). In part this reflects the fact that the test homes were selected because previous moisture-related problems had been noted by the occupants. However, of those households contacted to participate in this study, about one-third were selected, so moisture problems would appear to be rather prevalent in the general stock of new energy-efficient homes built in the region. Problems with ventilation and dehumidification equipment (notably air-to-air heat exchangers) were reported by more than half the occupants. Mold and mildew were reported by just under half. Later observations by the inspecting engineers verified that numerous moisture problems were indeed in existence.

While the occurrence of water-leak damage was not particularly extensive, the inspecting engineers observed a large number of other moisture problems not associated with leaks in about two-thirds of the homes (see Table 5). One-third of the homes had mold and mildew. It was observed on window frames, walls, and ceilings in all types of rooms, although it was especially prevalent in bedrooms (see Figures 1 and 2 for examples). It typically occurs when the relative humidity in a room is above about 60-70%. That type of moisture damage is not only a nuisance, it also causes additional maintenance and repair costs, such as for cleaning or repainting, and is associated with health problems (duPont and Morrill 1989).

Statistical data analysis of these results indicated that indoor moisture problems were very prevalent in the smaller houses, especially if the number of occupants was high. The analysis also showed that high indoor relative humidities, which are most likely to occur in small, heavily occupied homes, are strongly associated with increased interior moisture damage problems. The occurrence of mold and mildew was also related to the number of showers taken per day, which is another direct indication of the lack of indoor moisture control.

These results suggest that the ventilation systems were not doing an adequate job of removing excess moisture, and so relative humidities were too high. Reducing the incidence of mold and mildew will require lowering indoor relative humidities by improving moisture control.

TABLE 3
Occurrence of Indoor Moisture Problems and Damage

	Percentage of Homes in Each Region with Problems			
Moisture Problem	Cold	Coastal	Metro	All
Condensation on glass/frames	100	50	68	72
Mold/mildew on glass/frames	30	31	32	31
Moist. damage on window sills	35	25	16	22
Mold/mildew on other surfaces	50	25	30	34

TABLE 4
Previous Moisture Problems Reported

Reported	83%
Ventilation/dehumidification	53%
Mildew/mold	45%
Leaks	31%
Water stains	30%
Non-window condensation	28%
Musty odor	23%
Ice buildup	22%
Buckled siding	22%

TABLE 5
Other Moisture Problems Observed

None observed	37%
Downspouts not connected to storm sewer or suitable outfall	37%
Mold/mildew	34%
Staining	23%
Standing water in crawl space	16%
Warped siding	15%
Wood stored in basement/house	12%
Regularly used humidifier	8%
Blistering/peeling	5%

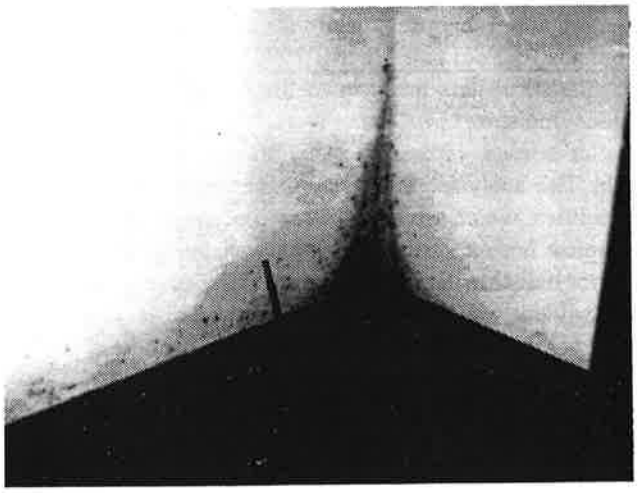


Figure 1 *An example of typical wall mold and mildew in a bedroom.*

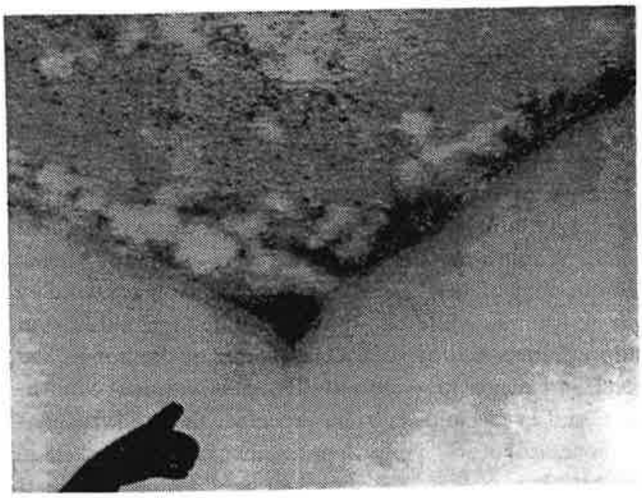


Figure 2 *An example of severe ceiling mold and mildew in a bedroom.*

Ventilation System Observations

During the inspections of the test homes, all ventilation systems were observed, including air-to-air heat exchangers (AAHX), bathroom and kitchen exhaust fans, as well as their controls. Dehumidifiers also were inspected. Simple checks of all systems were made to see if they were working. In addition, the use patterns of each system were determined during the occupant interview. Finally, the occupants were asked about previous ventilation and dehumidification problems.

The ventilation system observations were undertaken to provide information that might help explain the incidence of moisture-related problems within the test homes. This aspect of the moisture study was not meant to be a thorough ventilation study. While it was observed during the course of the inspections that the ventilation systems often were not working properly, insufficient test data were collected to clearly determine the impact on moisture-related problems. Considerable additional work is needed to do that. A thorough moisture control system study would appear to be in order and a major need.

Air-to-air Heat Exchangers While 86% of the test homes had an AAHX, 11% of them were not used regularly (see Table 6). Moreover, another entirely different 11% of them did not work at all. Thus, overall there was no AAHX ventilation in about one-third of the homes. Although most systems did work, numerous design, installation, and operational problems made them very ineffective in controlling moisture. Furthermore, the fact that they did not work or were not used was found from the statistical analysis of the results to lead to higher wall cavity moisture levels. If AAHX systems are to be installed in future energy-efficient homes, considerable thought and study must be given to their proper design, installation, testing/inspection, and operation. With that, the vast majority of the AAHX problems that were so prevalent could be avoided. Given that AAHX are no longer required in new homes in the Northwest and now seldom installed, there is all the more need to make sure that there are other well-tested systems or strategies available to properly control indoor moisture levels.

Air-to-air heat exchangers were installed in these test homes to provide ventilation that would mitigate indoor air quality problems. They were not specifically designed for moisture control. Unfortunately, it is not clear if even the best, properly used AAHX can satisfactorily remove moisture and control indoor relative humidities in the mild coastal and metro climates. This is because the outdoor air that "dries" the indoor air as a result of ventilation and air leakage is relatively moist during mild weather (especially during the fall and spring) and thus ineffective in flushing away moisture generated indoors (Tsongas 1987). Even exhaust-only ventilating systems may be inadequate for moisture removal and control. It would appear that some method other than ventilation is necessary to provide satisfactory indoor moisture control, especially in mild and humid climates and perhaps even in cold climates during mild weather.

Kitchen Ventilation There were numerous types of kitchen ventilation systems, and 8% of them did not work (see Table 7). A number of the kitchen fans were of the non-exhausting, recirculating variety that provide no removal of kitchen moisture. Some of the types that utilized the AAHX system often were not on when needed. Moreover, 40% of the occupants said they did not use the system when cooking, largely because they did not see the need. Many thought the major purpose was to get rid of cooking odors, and when there were no odors, there was no need to use the system. Overall there was no kitchen ventilation in almost two-thirds of the homes.

Numerous other problems kept occupants from using the kitchen ventilation system. If dehumidistat controls were installed on kitchen ventilation systems, moisture would be exhausted automatically when necessary, and the occupants would not need to be relied upon to turn on the system at the appropriate times. The installation of range hood recirculating fans that do not exhaust to the outdoors should be prohibited.

Bathroom Ventilation About 8% of the homes did not have a bathroom exhaust fan (see Table 8). Occupants were supposed to open the bathroom window for moisture control. This practice seldom provides satisfactory bathroom moisture removal. Of the homes that had a bathroom exhaust fan, 62% were connected to the AAHX. However, 20% of the bathroom exhausts connected to an AAHX did not work, and 9% of those systems with just an exhaust fan did not work. In all, 23% of these brand new homes did not have bathroom exhaust capability. It is believed that inade-

TABLE 6
AAHX System Problems

Did not exist	14%
Did not work	11%
Not used regularly	11%

No AAHX ventilation in about one-third of homes

TABLE 7

Kitchen Ventilation Problems

Did not work	8%
Nonexhausting, recirculating type	13%
Not used regularly/poorly controlled	40%
No kitchen ventilation in almost two-thirds of homes	

TABLE 8

Bathroom Ventilation Problems

Did not exist	8%
Connected to AAHX	62%
Did not work	20%
Exhaust fan only	30%
Did not work	9%
Lack of exhaust capability	23%
Not used often for showering or bathing	25%
No bathroom ventilation in half of homes	

quate control and insufficient fan capacity coupled with small diameter flex duct runs are the causes.

Moreover, 25% of the systems were not used often for showering or bathing. Thus, overall there was no bathroom ventilation in about half of the homes. Control with a properly calibrated dehumidistat would automate the removal of moisture when humidity levels are too high. In that way, occupants would not need to remember to turn on the exhaust fan or even know that it was important to do so to remove moisture generated in the bathroom. Incidentally, such an approach should be especially effective in controlling moisture levels in homes because it would be removing moisture directly at one of its sources.

Measured Flow Rates Bathroom exhaust flow rates were measured in the 26 coastal and metro homes revisited during the summer of 1988 and also remeasured in the 16 homes revisited in the winter of 1989. A flow hood specially designed to measure low flow rates was utilized. For the 36 bathroom exhaust fans, the mean measured flow rate was found to be 53% of the rated capacity. Thus the actual system performance is markedly poorer than the rated performance of the fan alone. The 14 fans with the lowest rated flow rate (50 cfm) achieved the lowest percentage of the rated capacity (45%), whereas the fans with the largest capacity achieved the highest. The 14 AAHX-only systems without a separate bathroom fan were characterized by relatively low flow rates, many of which were below 10 cfm or had no flow. The mean flow rate for those 14 AAHX exhausts was 20 cfm, which is about half the mean flow rate for the 36 bathroom exhaust fans.

These bathroom exhaust fan results are in general agreement with the results of field measurements of 10 fans in existing, conventionally constructed homes (Robinson and Rooke 1989); in that study, the average measured cfm to rated cfm percentage was 40%. A separate study of 50 cfm fans in 22 new energy-efficient homes in Oregon and Washington found the average actual flow to be 70% of the rated capacity (BPA 1989). A Canadian study of 19 bathroom exhaust fan installations found measured actual flow rates were on average 44% of the rated flow (HRAI 1988).

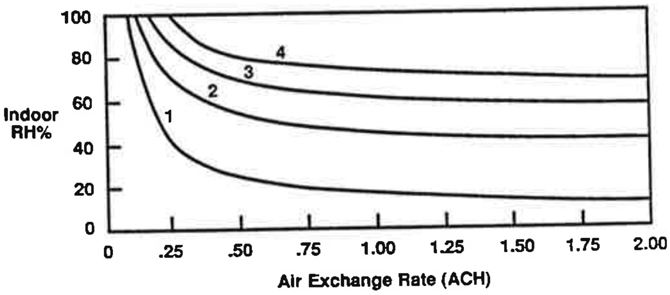
In addition, there is another, often neglected factor that greatly influences the effectiveness of any ventilation system. Operation of an exhaust fan changes the pressure distribution in a room. Some of the air that was exfiltrating when the fan was off is mechanically exhausted when the fan is on. Thus the real additional ventilation of the house is less than the airflow when an exhaust fan is turned on is less than the airflow through the fan system. The net ventilation is only about half of the flow through the exhaust fan system. For example, if a 40 cfm airflow is measured through a bathroom exhaust fan (rated, say, at 80 cfm), the real additional ventilation of the house is only about 20 cfm. This effect has been measured.*

The conclusion is that bathroom exhaust systems do not ventilate anywhere near as well as expected. Coupled with the fact that about one-quarter of the test homes did not have bathroom exhaust capability and another one-quarter were not used for showering or bathing, it is clear that moisture removal in bathrooms is poor and inadequate. A solution would be to use larger capacity, more expensive, quiet fans and/or larger duct sizes and no flex duct, with automatic bathroom fan operation when needed with either a dehumidistat or a timer.

*Private communication, Larry Palmiter, Ecotope, Seattle, WA.

Dehumidifiers A dehumidifier was used regularly in the wintertime to remove moisture in 16% of the homes. Surprisingly, 8% of the homes regularly used a humidifier, which in a few cases simply was a vaporizer. Use of a properly selected dehumidifier could be one of the most effective methods of removing moisture from homes in the mild coastal and metro climates. Indoor relative humidities are highest when outdoor temperatures are mild because the outdoor air is relatively moist and ineffective at drying out the indoor air. Under those conditions, any mechanical ventilation system will be relatively ineffective for moisture control and dehumidification may be necessary.

The influence of climate and weather on the effectiveness of ventilation for indoor moisture control is shown graphically in Figure 3. A microcomputer program (Tsongas 1987) was used to predict the variation of indoor relative humidity versus a building's air exchange rate for differing climates. A 1200-ft^2 (112-m^2) house with an internal moisture production rate (MPR) of 20 pounds per day (9 kg per day) and a fixed indoor temperature was assumed. The outdoor temperature and relative humidity values were varied from a cold, dry climate (case 1) to a mild, humid climate (case 4). Case 2 represents typical average winter conditions in Portland, Oregon, whereas Case 3 represents typical average winter conditions in the coastal region. The results show that it is relatively easy to maintain fairly low indoor relative humidities in cold, dry climates, and, in tightly constructed homes, ventilation can be effective at reducing indoor relative humidities if they are too high. On the other hand, homes in mild, humid climates have very high indoor relative humidities, and even excessive ventilation will have little effect on those levels. This also clearly shows that the times when indoor moisture levels and associated problems such as mold are the worst



		1	2	3	4
Outside Air Temp.	(Deg. F.)	20	47	52	58
Outside Air R.H.	(%)	50	76	90	90
Indoor Air Temp.	(Deg. F.)	68	68	68	68
Indoor M.P.R.	(Lb. $H_2$0/Day)	20	20	20	20
Bldg. Floor Area	(Sq. Ft.)	1200	1200	1200	1200
Ceiling Height	(Ft.)	8	8	8	8

Figure 3 *Effect of climate and weather on ventilation effectiveness.*

is during the mild spring and fall weather. Hence, for mild and humid climates, dehumidification appears to be necessary to maintain satisfactory indoor relative humidity levels.

An unanswered question is: What is the proper mix of dehumidification and ventilation? Until recently, little has been known about the non-summer performance of residential dehumidifiers. Field research (Tsongas and Wridge 1989; Galbraith 1986; Sanders 1985) has shown that a dehumidifier can effectively control indoor moisture levels in mild, humid climates during non-summer conditions. Thus the best moisture control system would appear to be a combination of dehumidification for general whole-house moisture removal and spot ventilation for moisture removal at bathroom and kitchen sources.

Unfortunately, it is not certain whether the dehumidifiers used in the test homes of this study were removing the moisture from indoor air effectively. In order to accomplish this when indoor air is at typical indoor winter temperatures, it is necessary to use a dehumidifier that is oversized relative to those that are used primarily in the summer, and the unit should have an automatic defrost control. Without the defrost control, the coil will frost or freeze up, and the water removal rate will drop or cease. Many commonly purchased dehumidifiers do not have a defrost control. Unfortunately, no check was made of the units originally installed for defrost control or high capacity.

Other Findings The existence and use of fireplaces and wood stoves (or fireplace inserts) resulted in some unknown degree of ventilation and subsequent drying of the indoor air. Wood stoves or fireplace inserts were found in 42% of the test homes, and 77% of those were used regularly. Numerous occupants commented about the "dry" heat from a wood stove. That may be because rooms with wood stoves in use are often rather warm, leading to lowered relative humidities and the perception of drier air.

Based upon conversations with the occupants, many do not understand their house's ventilation systems, particularly with regard to how and why they should be operated. Seldom is there even an instruction manual, although there should be since tight homes are different from conventional housing. In many cases, the occupants do not understand where moisture comes from, nor do they perceive the need to use exhaust fans or an AAHX to remove moisture in their airtight homes. Thus there is a huge need to educate the occupants on how and why to operate their moisture control systems. It even may be necessary to install inexpensive indoor relative humidity gauges in each home so the occupants will be able to know whether their home is too moist.

Given the large percentage of the test homes that had ventilation system components that did not work properly or at all, it is evident that building code inspectors missed those basic ventilation system problems. They need to be trained to inspect ventilation systems and to understand their importance in airtight homes that require proper moisture control.

CONCLUSIONS

The purpose of this study was to determine if moisture-related problems exist in heavily insulated, relatively airtight new Northwest homes. Based upon careful inspections of the test homes and their ventilation systems, as well as interviews with the occupants, numerous moisture-related problems and damage were noted inside the test homes.

The widespread incidence of so many different kinds of indoor moisture problems was much higher than expected in new homes. The data analysis showed that their existence correlated with high indoor relative humidity, which appears to be directly related to the fact that the ventilation systems, including spot exhaust fans and air-to-air heat exchangers, often were not working properly or not used. Of the bathroom exhaust fans that did work, the actual exhaust flow of the systems, including ducts, that were measured was only about half of the rated capacity of the fans.

There were many homes whose indoor relative humidities were clearly too high, with values reaching as high as 85% in a cold bedroom. These high readings, along with the findings of interior moisture-related problems, directly indicated that ventilation did not provide satisfactory moisture control in many of the test homes.

All these ventilation system problems resulted in inadequate removal of excess moisture and are especially disappointing since these homes were intended to include the best available ventilation systems that would result in well-controlled indoor conditions. Unfortunately, far too little attention was given to making the ventilation systems work properly, to including systems that would provide indoor moisture control in addition to ventilation just for satisfactory indoor air quality, and to educating the occupants in their proper use and need for moisture control.

For both new and existing tightly constructed homes in the mild western portions of the Northwest, adding a portable dehumidifier appears to be one of the best ways to provide satisfactory indoor moisture control. In the mild climates of the Northwest, ventilation alone will probably not provide adequate moisture control because the mild, humid outdoor air that is brought in to flush out the moist indoor air is often almost as moist as the indoor air, making ventilation not very effective for drying the indoor air. In such climates, the use of ventilation alone for moisture control probably should be discouraged. Since ventilation is still required to provide adequate indoor air quality, a combination of ventilation and dehumidification is needed. An equally important component of the overall solution is either providing moisture controls that operate automatically or educating the occupants to be aware of the need for moisture control in these airtight homes when systems that do not work automatically are installed. It appears that dehumidification, in combination with spot ventilation with automatic control, should be considered as a major part of a moisture control strategy for all coastal and metro homes and perhaps even some cold-climate homes for use during mild weather.

The surprisingly large number of moisture problems reported in these new homes is disturbing. These results suggest that moisture problems may be prevalent inside many new homes. Not enough attention had been paid to controlling excess moisture in tight homes, and there is a definite need to improve their indoor moisture removal capability. To not do so will result in continuing indoor moisture-related problems and possibly even long-term structural damage within walls. For future as well as existing energy-efficient airtight homes, moisture control must have a much higher priority in their design, construction, inspection, and ongoing operation. This goal appears achievable.

RECOMMENDATIONS

Recommendations for Further Study

A number of important questions arose from this study.

1. What needs to be done to provide the satisfactory indoor moisture control that is so lacking in tightly constructed Northwest homes? Are the existing ventilation systems capable of maintaining satisfactorily low indoor relative humidity levels if they work properly and are used as intended? Is the use of air-to-air heat exchangers or whole house exhaust-only ventilation systems workable as a moisture-removal strategy during mild seasons in cold climates or in mild climates where the outdoor air often is almost as moist as the indoor air? Should dehumidifiers be used to augment spot ventilation to provide the necessary removal of moisture in new tight homes in mild climates or during mild seasons in cold climates?
2. Can simple and inexpensive controls, such as dehumidistats or automatic timers, be installed on bathroom and kitchen exhaust fans to effectively automate the removal of moisture generated at the source and result in proper and automatic control of indoor moisture levels?
3. Given that existing bathroom exhaust fan systems achieve only about half of their rated exhaust flow, are there simple and inexpensive ways of modifying the ducting or other components to increase the flow, or must larger capacity (cfm) fans be used?
4. Are indoor moisture problems even more prevalent in new multifamily residences that are smaller in size and thus are theoretically more prone to moisture problems?

These questions need to be answered to conclusively determine if interior moisture problems can be prevented in new homes built with heavily insulated walls, a continuous air-vapor barrier, and mechanical ventilation with or without heat recovery. Even though it has been found that current energy-efficient home construction practices cause indoor moisture problems, remedial actions appear possible. But what works best? Clearly, additional information is needed.

Proposed Tests and Studies

1. Undertake a limited moisture field study of a small number of relatively new, tightly constructed multifamily houses, particularly in the coastal or metro regions, to see if they have similar or worse problems, as expected.
2. Test the effectiveness of a combination of ventilation and dehumidification for indoor moisture control in mild, humid climates. This could be easily accomplished by comparing the indoor relative humidity performance of identical side-by-side apartments, one with dehumidification and one without. Two unoccupied apartments could be rented for the duration of the study. Equal moisture production could be achieved with vaporizers or humidifiers.
3. Test the effectiveness of dehumidistat and other automatic controls installed on bathroom and kitchen exhaust fans at maintaining proper indoor moisture levels.
4. Test the effect on bathroom exhaust fan system flow of increasing the duct diameter and replacing flex duct with nonflex duct. Determine the cost to modify existing ducts.

Practical Recommendations to Improve Indoor Moisture Control

To transfer the findings and conclusions of this study so they may be of practical use to the building community at large, specific recommendations have been made to builders and contractors, building code officials, and occupants of energy-efficient homes. These rather extensive recommendations are presented in detail in Tsongas (1990), which is available from the author or BPA, and are not repeated here because of space restrictions. The primary focus of those recommendations is on providing specific practical suggestions to help improve indoor moisture control and reduce the incidence of indoor moisture problems.

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